E. A. POLUMBUS, Jr.

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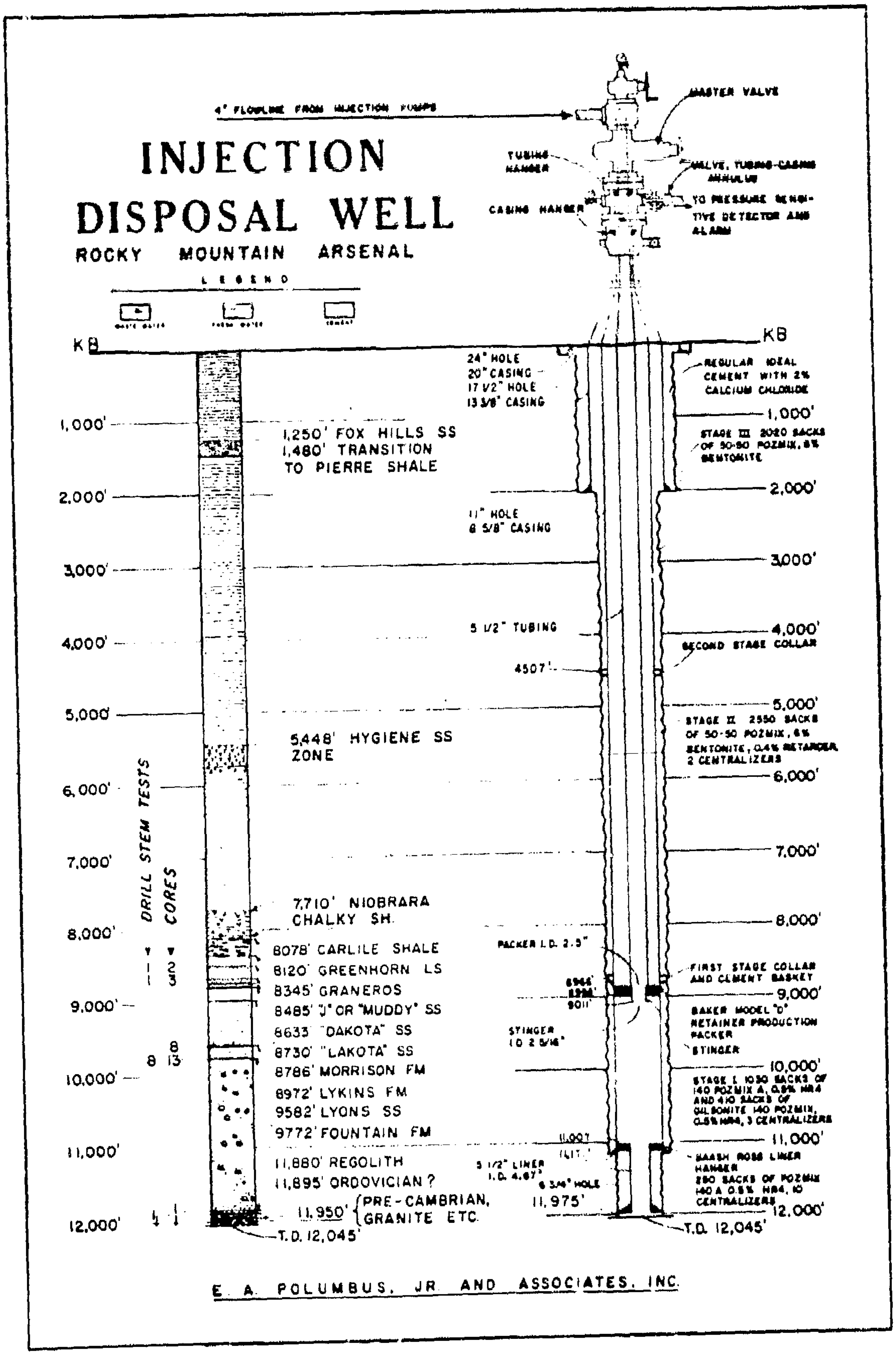
AD 667358

FINAL REPORT ON DRILLING OF PRESSURE INJECTION DISPOSAL WELL ROCKY MOUNTAIN ARSENAL DENVER, COLORADO

Prepared for
Department of the Army
U. S. Army Engineer District, Omaha
Corps of Engineers

Prepared by
E. A. Polumbus, Jr., and Associates, Inc.
Design and Management Engineers
Denver, Colorado - November 30, 1961

Contract DA-25-066-ENG-6033



INJECTION DISPOSAL WELL
ROCKY MOUNTAIN ARSENAL
LEGEND
4" FLOWLINE FROM INJECTION PUMPS
MASTER VALVE
TUBING HANGER
VALVE, TUBING-CASING ANNULUS
CASING HANGER
TO PRESSURE SENSITIVE DETECTOR AND ALARM
KB
1,000'
2,000'
3,000'
4,000'
5,000'
6,000'
7,000'
8,000'
9,000'
10,000'
11,000'
12,000'
DRILL STEM TESTS
CORES
1,250' FOX HILLS SS
1,480' TRANSITION TO PIERRE SHALE
5,448' HYGIENE SS ZONE
7,710' NIOBRARA CHALKY SH.
8078' CARLILE SHALE
8120' GREENHORN LS
8345' GRANEROS
8485' "J" OR "MUDDY" SS
8633' "DAKOTA" SS
8730' "LAKOTA" SS
8786' MORRISON FM
8972' LYKINS FM
9582' LYONS SS
9772' FOUNTAIN FM
11,880' REGOLITH
11,895' ORDOVICIAN ?
11,950' PRE-CAMBRIAN, GRANITE ETC.
T.D. 12,045'
24" HOLE
20" CASING
17 1/2" HOLE
13 3/8" CASING
REGULAR IDEAL CEMENT WITH 2% CALCIUM CHLORIDE
STAGE III 2020 SACKS OF 50-50 POZMIX, 8% BENTONITE
11" HOLE
8 5/8" CASING
5 1/2" TUBING
4507'
SECOND STAGE COLLAR
STAGE II 2550 SACKS OF 50-50 POZMIX, 6% BENTONITE, 0.4% RETARDER, 2 CENTRALIZERS
PACKER I.D. 2.5"
FIRST STAGE COLLAR AND CEMENT BASKET
9011'
BAKER MODEL "D" RETAINER PRODUCTION PACKER
STINGER I.D. 2 5/16"
STINGER
STAGE I 1050 SACKS OF 140 POZMIX A, 0.5% HR4 AND 410 SACKS OF GILSONITE 140 POZMIX, 0.5% HR4, 3 CENTRALIZERS
11,007'
5 1/2" LINER I.D. 4.67"
6 3/4" HOLE
11,975'
BAASH ROSS LINER HANGER
280 SACKS OF POZMIX 140 A 0.5% HR4, 10 CENTRALIZERS
T.D. 12,045'
E. A. POLUMBUS, JR. AND ASSOCIATES, INC.

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PURPOSE

The purpose of this report is to provide the United States Army Corps of Engineers, Omaha District, and the United States Army Chemical Corps with a readily accessible, discernible, and definitive record of all data, activities and events relating to the drilling and completion of the Rocky Mountain Arsenal Pressure Injection Disposal Well. It is intended that this report serve as a comprehensive reference, sufficiently complete to cover minute details, and yet arranged in such a manner that the most salient aspects of the operation may be examined independent of details. The report is presented in three volumes. Volume I includes discussions of the operation from the design phase through the final completion. Detailed statistical and tabular data are included in Volumes II and III.

It is not the intent of this report to discuss the initial injection operations. This is to be covered in detail in a subsequent report of the initial fluid injection characteristics.

ABSTRACT

The Rocky Mountain Arsenal Pressure Injection Disposal Well was drilled for the United States Army Chemical Corps by the United States Army Corps of Engineers, Omaha District. The firm of E. A. Polumbus, Jr., and Associates, Inc., served as consulting and management engineers and consulting geologists to the Corps of Engineers in the design, drilling, and completion of the well. The well was drilled to provide access to underground strata which could be used as waste disposal reservoirs.

Drilling operations on the well, which is located on the Rocky Mountain Arsenal grounds, commenced on March 10, 1961. Loffland Brothers Company was contracted to drill the well. The well was drilled to a total depth of 12,045 feet terminating in crystalline rocks of pre-Cambrian Age. The drilling rig was released on September 28, 1961, and the construction phase of the drilling well operation was considered completed on November 30, 1961, when the well head equipment was installed and the well turned over to the Chemical Corps. This report covers the operation to this stage.

In the design and drilling of the well and in the identification, evaluation, protection, and testing of potential injection reservoirs, broad adaptations of tools, techniques and practices developed in the oil industry were required.

Problems resulting from natural characteristics of the formations penetrated ranged in severity to economically serious and critically hazardous. Exposure to drilling fluids of the long shale section from 2,020 feet to 8,485 feet for a relatively long period of time, coupled with lost circulation in lower formations, created an intricate and difficult mud control problem as well as a keyseating problem. The highly fractured formations occurring frequently from 9,600 feet to total depth resulted in coring difficulties, and a reduction in the desired number of drill stem tests as well as lost circulation problems. The quartzitic nature of the rocks below 9,600 feet resulted in slow penetration necessitating the use of a large number of drill collars to achieve high drilling weights, high bit consumption and high frequency of roundtrips to great depths with the drill string. Combinations of the above adverse drilling factors resulted in the necessity of setting the 8 5/8-inch long string of casing at 11,171 feet instead of 11,400 feet. This in turn necessitated setting a 5 1/2-inch liner in the open hole below the 8 5/8-inch casing for which no provision was made in the original program.

During the drilling of the well, all formations were critically examined, and where possible, those showing any potential as injection reservoirs were cored and drill stem tested. A total of 639 feet of formation were cored and 14 formation tests were attempted. The injection reservoirs with the greatest indicated potential to accept fluids were found

below 9,600 feet in fractured portions of the Lyons and Fountain formations and in the pre-Cambrian rocks.

To accommodate the specified injection volume of 400 to 800 gallons per minute at 2,000 psi surface injection pressure and to isolate effectively the potential injection reservoir from shallow fresh water-bearing beds, 20-inch casing was set at 135 feet; 13 3/8-inch casing at 2,020 feet; 8 5/8-inch casing at 11,171 feet, and a 5 1/2-inch liner placed from 1[illegible],007 feet to 11,975 feet. To insure complete isolation, each string of casing was sheathed with cement for its entire length. Injection of fluids is made through 5 1/2-inch tubing set in a packer at 8,998 feet.

The well was completed with the open hole section in the fractured pre-Cambrian rocks from 11,975 to 12,045 feet serving as the present injection zone. Preliminary injection tests showed the zone to be capable of initially accepting the desired volumes of fluid.

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DESIGN CONSIDERATIONS (III)

DESIGN CONSIDERATIONS

INTRODUCTION

Disposal of waste fluids from chemical plants at the Rocky Mountain Arsenal was first recognized as a problem of major consequence when it was found that unsealed evaporation pits permitted leakage into shallow aquifers, contaminating an important water supply near the surface. In order to meet this emergency the Chemical Corps of the U. S. Army sealed a large earthen pond, designated as Pond F (See Figure 1 for location) and commenced accumulating waste effluent into it. The rate at which the waste material accumulated exceeded the rate of evaporation to the extent that the capacity of Pond F was expected to be reached in late 1961. Alternative methods for handling these waste fluids on a more permanent basis in the future were considered by the Chemical Corps, and it was decided to drill a deep pressure injection disposal well near Pond F. The design and drilling of this well were assigned to the U. S. Army Corps of Engineers, Omaha District.

The feasibility of disposing of chemical waste fluids from industrial plants and refineries into subsurface reservoirs has been well established. It is not uncommon to seek suitable injection reservoirs at depths approaching 7,500 feet although the preponderance of wells drilled specifically for this purpose has been considerably shallower.

The design and drilling of a disposal well at the Rocky Mountain Arsenal involved broad adaptations of techniques, practices, and equipment employed in the petroleum industry. In like manner, the identification, evaluation, protection, and testing of potential injection reservoirs in the well required the application of drilling technology, petroleum engineering, and geological practices developed in the petroleum industry.

The Corps of Engineers, therefore, engaged the consulting petroleum engineering firm of E. A. Polumbus, Jr., and Associates, Inc., under an Architect Engineer type contract (Contract No. DA-25-066-eng-6033) to design the injection well, supervise the drilling, provide the necessary engineering and geological services, and manage the project.

The basic design specifications were to locate, evaluate, and provide access through a well bore to an underground reservoir or reservoirs near Pond F. The underground storage facilities were required to be capable of accepting partially treated waste fluids for a number of years at rates up to 800 gallons pe minute at a maximum surface injection pressure of 2,000 psi.

The proposed design for the Rocky Mountain Arsenal Pressure Injection Disposal Well was presented in the "Final Design Analysis" submitted to the U. S. Army Corps of Engineers, Omaha District, by E. A. Polumbus, Jr., and Associates, Inc., on July 5, 1960.

OBJECTIVE DISPOSAL RESERVOIRS

Eight geologic formations, or units, underlying the Arsenal grounds were considered as possible injection reservoirs. These are: the Hygiene sandstone, the Codell sandstone, the "J" sandstone, the Dakota sandstone, the Lakota sandstone, the Morrison formation, the Lyons formation, and the Fountain formation. The preliminary estimates indicated that a complete penetration of the Fountain formation, terminating in pre-Cambrian rocks, would require the drilling of an 11,400 foot well.

CASING AND HOLE PROGRAM

The casing and hole program set forth in the Final Design Analysis is summarized as follows:

Depth	Hole Size	Casing Size	Tubing Size
125'	24 "	20 "	
2,000'	17 1/2"	13 3/8"	
11,400'	11 "	8 5/8"	
9,865'			5 1/2"

Since the exact depths of the formations or the exact reservoir to be used for injection would not be known in advance, the program was based on setting the long string of casing to the predicted total depth at the top of the pre-Cambrian rocks with the tubing set at the top of the Fountain formation.

The selection of 5 1/2-inch tubing involved equating horsepower requirements as related to capital investment and operating costs of surface plant facilities versus well costs for the different casing programs.

The basic specifications regarding injection rates and pressures versus the pressure drop in the tubing were an integral part of these considerations.

The selection of 5 1/2-inch tubing as the injection string established the requirement for 8 5/8-inch casing when the various mechanical limitations and tolerances were considered. The use of 8 5/8-inch casing in turn dictated the need for drilling an 11-inch hole.

The program requirements for the 13 3/8-inch and 20-inch casings likewise reflected the basic requirement for 5 1/2-inch tubing when all mechanical factors and an allowance for flexibility of the program were considered.

Since contamination and potential contamination of shallow potable water bearing sands with waste effluent was one of the principal factors influencing the decision to drill the Arsenal well, precautions against similar contamination in the well itself were taken. Thus, to prevent migration of waste fluids from lower injection horizons into the shallow sands through the annulus between the well bore and the casing, a program of placing cement behind each string of casing from the casing shoe to the surface of the ground was adopted.

MUD PROGRAM

The anticipated geologic section included a long shale interval from the surface to approximately 8,200 feet, stratigraphically above the principal objective disposal reservoirs. With the overall economics of the

disposal project as a dominating influence, a mud program was designed that within practical limits would prevent this shale section from swelling and caving during the long period it would be exposed while drilling and extensively testing the lower potential injection reservoirs. The mud program was designed also to minimize damage to potential injection zones.

EVALUATION PROGRAM

A more elaborate program of coring, drillstem testing, electric logging, and other data accumulation was necessary in the Rocky Mountain Arsenal well than is normally followed in a well drilled for the sole purpose of obtaining hydrocarbon production. The Arsenal well not only required the identification of any hydrocarbon bearing beds, in order to avoid contamination with waste waters, but also required the gathering of data on all zones offering injection possibilities. All potential reservoir rocks had to be identified and evaluated as drilling progressed since this was a singular operation that could neither be repeated nor could information be substituted from other wells, because of the remoteness of previous drilling operations in the area.

An examination of the cuttings samples, the various electric logs, the mud log record, and the drilling records were programmed to provide full coverage of the total interval of the well. For special evaluation of zones of particular interest fifteen cores totalling 750 feet of section and fourteen drillstem tests were scheduled.

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GEOLOGY (IV)

GEOLOGY

The following discussion is confined to basic geologic considerations regarding the regional geology, as well as the stratigraphic relationships and lithology of the strata which were encountered. More detailed discussions of physical geologic data and the application of these data to the problems in selecting injection reservoirs are included in the section of this report entitled "Prospective Injection Reservoirs."

REGIONAL GEOLOGY

The Rocky Mountain Arsenal Pressure Injection Disposal Well was drilled approximately 12 miles northeast of the city of Denver, Colorado, (Figure 2). It is situated a short distance to the east of the axis of the Denver-Julesburg Basin. As determined from surface geological observations, shallow and deep well drilling, and geophysical surveys, the Denver-Julesburg Basin is a north-south trending "trough" or asymmetrical syncline. Strata which are exposed along the mountain front dip steeply eastward. On the east flank of the basin, the strata dip gently westward from the plains of Nebraska and eastern Colorado. As shown on Figure 3 the disposal well lies near the structurally lowest part of the basin, and where the greatest thickness of sedimentary rocks is known to be present.

The Front Range of the Rocky Mountains came into being near the close of the Cretaceous period. As the mountains were formed, the mountain block was elevated and thrust eastward over the sediments of

the adjacent plains. The Cretaceous and older sedimentary rocks of the basin are thus separated from the pre-Cambrian crystalline rocks of the mountain uplift by a fault of system of faults which extends from Canyon City, Colorado, northward to the Wyoming-Colorado state boundary and beyond. At places, the stratigraphic displacement along this fault exceeds 10,000 feet. The diagrammatic cross sections (Figures 4 and 4A) show the structure at the mountain front and the relationship between the subsurface rocks at the Arsenal well and the strata which are exposed at the mountain front.

STRATIGRAPHIC GEOLOGY

As the well was being drilled, samples of drill cuttings were taken from the mud stream, washed, and saved at ten foot or lesser intervals. Rock cores were also cut at selected intervals. The sample cuttings were immediately examined with a binocular microscope and under fluorescent light by the well-site geologist. Detailed lithologic descriptions of the sample cuttings are presented in Volume III of this report. The lithology of the cores is described with the samples, and also in Table 2 of Volume I.

Data from the samples and cores, together with interpretations of electric and drilling time logs, provide fundamental information regarding the character and thickness of the formations penetrated in the well. The names and depths of the formations penetrated are shown on Table 1. Brief descriptions of the character of these formations are given in the following paragraphs:

The surface sediments at the well site are recent soils which form a thin cover over windblown sands and water-laid gravels and shales of Pleistocene Age. Below the Pleistocene sediments is a series of poorly consolidated sandstones, arkoses, and dark gray shales of early Tertiary and latest Cretaceous Age. These materials comprising these beds were derived in a large part from the rocks which were eroded from the uplifted mountain block which lay to the west. The rock debris was carried eastward by flowing streams and was deposited in lakes and low lands east of the mountains. These sediments are called the Arapahoe Formation, and with the surface and Pleistocene beds comprise the uppermost 460 feet of strata drilled in the well.

The Laramie Formation of Upper Cretaceous Age was penetrated in the disposal well between 460 and 1,250 feet in depth. It is composed of interbedded fine gray sandstones and dark gray and carbonaceous shales and some coal beds. The Laramie Formation grades downward into the Fox Hills Formation which was found between 1,250 and 1,480 feet in depth. The Fox Hills Formation is principally a buff, friable, porous sandstone with some sandy shale and clay shale. The Fox Hills, together with the sandstones which occur in the overlying sediments are important sources of potable water in the vicinity of the Arsenal and the city of Denver.

Immediately below the sandstones which yield fresh potable water (surface to 1,480 feet), there is a thick series of relatively impermeable

shales and limey shales of Cretaceous Age. These strata effectively segregate the shallow water-bearing sandstones from deeper porous strata into which waste fluids may be injected in the future. Between the depths of 1,480 feet and 8,485 feet in the Arsenal well, the Pierre shale (1,480 to 7,710 ft.), the Niobrara shale (7,710 to 8,078 ft.) and the Carlile shale, the Greenhorn limestone, and the Graneros shale (8,078 to 8,485 ft.) constitute an impervious barrier separating the water sandstones and the potential injection reservoirs.

The Pierre shale, 6,230 feet in thickness, is principally a black to dark gray shale of marine origin. At a depth of 5,448 feet in the Arsenal well, the Hygiene sandy zone was encountered. This zone at the Arsenal location is represented by a shaley sand of low permeability and porosity. The Niobrara shale is calcareous or chalky, light gray to gray in color and 368 feet thick. The Carlile shale is darker in color and less calcareous than the Niobrara; the Greenhorn limestone is dense, shaley, and gray to brown in color; the Graneros shale is black, micaceous, and contains thin beds of bentonite near the base. These latter three formations are all marine in origin and aggregate 407 feet in thickness in the Arsenal well. They are sometimes considered as a unit and are then called the "Benton Formation." The Codell sandstone, which is known to be erratically developed, was missing in the well.

The "J" sandstone, the principal oil producing sandstone of the Denver Basin, was the first of the objective sandstones encountered which

showed any significant development. In the Arsenal well it occurs in the interval, 8,485 to 8,605 feet, immediately underlying the Graneros shale. The upper 45 feet of this unit consists of quartzitic sandstone showing very slight oil staining. The remaining part of the "J" was found to be irregularly bedded and intermixed fine grained quartzitic sandstone and dark gray shale. Immediately below the "J" sandstone is a dark gray marine shale unit, 28 feet in thickness, called the Skull Creek Shale.

The Dakota and Lakota sandstones which were penetrated between 8,633 and 8.786 feet underlie the Skull Creek shale and are the lowermost units of Lower Cretaceous Age. The upper sandstone (Dakota) is of fine to medium grain size and is hard to quartzitic. It is separated from the Lakota sandstone by black shales and thin sandy strata. The Lakota sandstone is 56 feet thick and is a fine grained gray, quartzitic sandstone which grades downward into a somewhat sandy dark gray bentonite shale. These two sandstones are oil productive in the northern portion of the Denver Basin, but are unproductive in the vicinity of the Arsenal well.

The Morrison Formation of Jurassic Age lies below the Lakota and was penetrated in the Arsenal well between 8,786 and 8,972 feet. It is composed of black, red, and green shales, with a few beds of limestone, hard white sandstone, and anhydrite. The Morrison does not produce oil or gas in the Denver Basin.

The Lykins Formation is Triassic in Age. It underlies the Morrison at depths of 8,972 to 9,532 feet. The predominant lithology of the Lykins

is reddish silty shale. A 15-foot bed of fine grained quartzitic sandstone occurs at the top of the formation, and at the base there is an 80-foot section of interbedded anhydrite, dolomite, and red silty shale.

The Lyons Formation of Permian Age is 190 feet thick in the Arsenal well. It was penetrated between 9,582 and 9,772 feet. The cores and cuttings samples showed it to consist of fine grained, well cemented to quartzitic, orange colored sandstone interbedded with red to maroon shale. Some of the sandstone cores exhibited cross-bedding. Numerous fractures were observed in the cores.

The Fountain Formation of Pennsylvanian Age is 2,108 feet thick in the Arsenal well. It was penetrated in the interval 9,772 to 11,880 feet. The uppermost 110 feet of this formation consists of fine grained, feldspathic sandstones, siltstones, and maroon shales. Below this interval the sediments are primarily arkosic sandstones, grits, and pebble conglomerates which are irregularly interbedded with shales and silty shales, all red to reddish brown in color. The clastics are cemented by calcareous material, by clay, or by a combination of both. Cores taken in the Fountain Formation revealed the presence of fracturing. Immediately below the Fountain Formation, a Regolith or "fossil soil" zone was penetrated from 11,880 to 11,895 feet. The regolith is composed primarily of weathered maroon to dark brown shale with a brown, fractured, quartzite bed forming the basal foot. The regolith is interpreted as being the ancient land surface upon which the Fountain Formation was deposited. (Figure 5)

Between the base of the regolith and the top of the rocks which were identified as pre-Cambrian (11,895 to 11,950 feet) there is a 55-foot section of quartz conglomerate, purple shale and pink dolomite whose age is not as yet definitely determined. Lithologic comparison with rocks of similar stratigraphic position which crop out in the Colorado Springs region indicates that the strata in question are Ordovician (?) or Cambrian (?) in age. The presence of these beds in the Arsenal well represents the northernmost known occurrence of Paleozoic sediments older than the pre-Fountain regolith along the west flank of the Denver Basin.

The pre-Cambrian rocks penetrated in the well are of two types--the uppermost rock which was drilled from 11,950 to 11,970 feet has the characteristics of aweathered schist.(Figure 5) In the drill cuttings, it has the appearance of a bright green shale containing an abundance of copper-colored mica and clay minerals. Immediately below the weathered schist, from 11,970 feet to 12,045 feet which is the total depth of the well, a crystalline rock identified as pre-Cambrain hornblende granite gneiss containing an intrusive pegmatite was drilled and cored. A core taken in the gneiss section showed vertical fracturing.

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PHYSICAL OPERATIONS

CHRONOLOGICAL SYNOPSIS

When reviewed in its entirety, the drilling of the Rocky Mountain Arsenal Pressure Injection Disposal Well was a complex operation. In order to facilitate an understanding of the inter-relationships of various phases of the operation that are discussed separately in other sections of this report, a brief historical chronology highlighting important events and developments from inception to completion of the project is set forth. Further clarification may be facilitated by frequent reference to two illustrations. The first is the frontispiece, which is a schematic drawing of the well. The second is a graphical representation of the drilling history, included as Figure 6. Another suggested reference is the detailed record of each day's operations included as a complete chronological log in Volume II.

Operations Prior to Drilling

E. A. Polumbus, Jr., and Associates, Inc., was first retained by the U. S. Army Corps of Engineers, Omaha District, in December, 1959, to prepare a preliminary design analysis for a deep well waste disposal project for the Rocky Mountain Arsenal to be used as a feasibility study. The preliminary design report, released January 6, 1960, included both the injection well and treatment plant facilities. Subsequent to receipt of this preliminary report, the overall project was divided into two parts for purposes of final design. The treatment plant final design was assigned

to A. J. Ryan and Associates of Denver, Colorado. The final design of the pressure injection well was assigned to E. A. Polumbus, Jr., and Associates, Inc., January 25, 1960, under contract No. DA-25-066-eng-6033. This contract provided not only for the final design of the injection well, but also included a provision requiring E. A. Polumbus, Jr., and Associates, Inc., to supervise the drilling of the well, render the necessary engineering and geological services during the construction phase, and manage the project.

Concurrent with the preparation of the final design report, E. A. Polumbus, Jr., and Associates, Inc., also prepared detailed drilling specifications and drilling contract details which became a part of the Invitation For Bids (Construction Contract) issued to drilling contractors. Additionally, the casing design requirements were prepared in advance for the Invitation Bid and Award (Supply Contract) forms issued by the Corps of Engineers to suppliers of tubular goods. The "Final Design Analysis" report was submitted to the Corps of Engineers on July 5, 1960.

On November 17, 1960, the first bid invitation was extended to drilling contractors and was based upon a footage type contract to 6,576 feet followed by day-work to total depth. Bids received in response to this invitation were unsatisfactory, and the Polumbus firm was called upon to arrive at a basis that would encourage more acceptable bidding. A second Invitation For Bids was issued on December 28, 1960, based on a day-work type contract.

The first issuance of Invitation Bid and Award (Supply Contract) for tubular goods occurred on November 10, 1960. This bid was subsequently cancelled and a new bid invitation for furnishing tubular goods was issued December 7, 1960. The opening date of the final bids for the drilling contract was January 26, 1961. The drilling contract was awarded to Loffland Brothers Company, Contract No. DA-6724, and the required spud date for commencement of drilling operations on the Rocky Mountain Arsenal Pressure Injection Disposal Well was March 15, 1961.

Representatives of the Polumbus firm attended all Bid-opening sessions for the purpose of assisting the Corps of Engineers in the analysis and evaluation of bids submitted.

On February 13, 1961, Loffland Brothers Company received notice to proceed. This immediately launched a series of operations, including preparation of surface location, roads, and mud pits, laying water line and moving in the drilling equipment. The location, officially surveyed on March 4, was previously selected by the Rocky Mountain Arsenal personnel northea [illegible] Pond F at a sufficient distance to provide room for the treatment plant facilities between the pond and the well site.

"Rigging up" operations which commenced March 1 proceeded under adverse weather conditions and delayed the spudding of the well until 3:45 a.m. March 10, 1961.

Preparatory to spudding and throughout the course of the operations, E. A. Polumbus, Jr., and Associates, Inc., handled the customary notices

of intention to drill, permits, and reports to the state of Colorado regulatory bodies dealing with the drilling of wells.

Drilling

Surface to Intermediate Casing Point (2,020 feet)

A 12 1/2-inch hole was drilled to 139 feet and reamed to a 24-inch diameter. The 20-inch surface casing was cemented at 135 feet. Sufficient cement was employed to provide a cement sheath from the bottom of the casing to the surface.

A 12 1/2-inch hole was then drilled to a depth of 2,030 feet. An Induction-Electric Log and Microlog were run in the open hole interval. The hole was then reamed to 17 1/2 inches. On March 18 the 13 3/8-inch casing was cemented at 2,020 feet. Sufficient cement was used to completely fill the annular space between the casing and the formation from the casing shoe to the surface.

This upper portion of the hole was drilled with a gel chemical type mud.

Intermediate Casing Point to "J" Sandstone (8,485 feet)

After converting the mud system to Driscose Condet mud, drilling proceeded with an 11-inch hole being cut. At this time, the Baroid mud logging unit was placed in operation.

In the drilling from 2,020 feet to the top of the "J" sandstone at 8,485 feet, 11.9 net drilling days were consumed (Figure 6) which

represents an average penetration rate of 543 feet per net drilling day. This was done in the March 23 to April 7 period.

While drilling at 6,000 feet, a twist-off occurred in the 4 1/2-inch drill pipe immediately above the drill collar assembly. The fish was recovered in 10 1/2 hours and drilling was resumed. Adjustments in rotary speed and other techniques were made to avoid a re-occurrence. This was the only fishing job for drill pipe during the entire course of the drilling operation.

The Baroid mud logging unit recorded a number of gas "kicks" in the Niobrara formation which are typical throughout the Denver-Julesburg Basin.

"J" Sandstone to Top of Lyons Formation (9,582 feet)

The drilling of an 11-inch hole continued through the 1,097-foot interval from the top of the "J" sandstone to the top of the Lyons formation. This was penetrated in the April 8 to May 3 period. The drilling and coring consumed 19.4 net drilling days, equivalent to an average penetration of 57 feet per day. (Figure 6)

Five cores, two in the "J" sandstone and three in the Dakota sandstone were cut in this interval. Slight oil staining was noted in the upper portion of the "J" sandstone.

Two drill stem tests in this interval recovered only small amounts of slightly gas cut mud. These tests covered the cored portion of the "J" sandstone and from near the top of the Dakota sandstone into the Morrison formation.

Of interest is the fact that the actual rig time from spudding the well to reaching the top of the Lyons formation at 9,582 feet exclusive of shut-down time for mechanical repairs to the rig, was within one day of the time forecast in the design.

Top of Lyons Formation to Bottom of 11" Hole (11,225 feet)

In the period from May 3 to July 21, the 11-inch hole was drilled and cored from the top of the Lyons formation to 11,225 feet in the Fountain formation, the top of which was encountered at 9,772 feet. Hole difficulties in the nature of key seating and lost circulation made advisable the setting of the 8 5/8-inch casing at 11,171 feet.

The drilling and coring of this 1,643-foot interval consumed 47.3 net drilling days. This is an average penetration of 35 feet per day.

Both the Lyons and Fountain formations were found to be exceptionally hard, which coupled with the presence of fracturing presented complex problems in drilling and coring.

In this interval, fourteen instances of lost circulation were noted. The mud losses per instance ranged from minor amounts to 1,350 barrels. Since it was believed that the mud losses occurred in fractured zones, an oilfield technique for "healing" lost circulation zone in fractured formations was successfully adopted. This involved discontinuing drilling and mud circulation, spotting a batch or "pill' of lost circulation material at the bottom of the hole, and allowing the well to set or "cure" for an 8 to 12-hour period.

Sixteen cores were cut in this interval of the Lyons and Fountain formations. In addition to lost ...lation problems the combination of hardness of the rocks and frac... g caused jamming or wedging in the core barrel, which generally preclu...ed the cutting of full-length 50-foot cores.

The combination of the various problems was such that a modification in the coring and testing program was instituted. Short cores at periodic intervals were accepted for geological examination and for determinations of physical properties. Instead of testing only th... cored intervals, the drill stem testing program was altered to attempt complete coverage of the section.

Due to a known tendency for the Lyons formation sandstones to produce fine sand into a wellbore during tests and the presence of fractures, with the consequent risk of sticking the test tool, no drill stem tests were attempted in the Lyons formation. One test with the Schlumberger Formation Interval Tester was unsuccessful due to the plugging of the tool with lost circulation material in the mud.

In the interval from the top of the Fountain formation to 11,225 feet, eight drill stem tests were run. At a driller's depth of 9,729 feet, an Induction-Electric log, a Sonic log, and a Microlog were run.

Setting of 8 5/8-inch Casing at 11,171 Feet

In drilling at 11,178 feet and below, tight hole and bridges in the hole were encountered in addition to the previous difficulties with lost

circulation and the extremely hard fractured rock. The tight hole and bridging problem became particularly noticeable when the hole reached a depth of 11,225 feet.

The deflection of the hole to a maximum of 3 1/4 degrees within the 6,700-foot to 8,000-foot interval was not severe or exceptional. However, during the long period of time the hole was exposed to frequent trips with the drill string, a groove or "keyseat" was worn into one side of the hole. The usual techniques were followed in reaming out the keyseat and included the placement of a reamer and keyseat wiper in the drill string.

The increased hazard represented by the presence of a keyseat coupled with the previously mentioned considerations led to a decision to set the 8 5/8-inch casing when the depth of 11,225 feet was reached rather than at 11,400 feet as originally scheduled.

An Induction-Electric log and Sonic log were run at the 11,225 foot depth. Due to the hazardous condition of the hole, other logging was not attempted.

The 8 5/8-inch casing was run and set at 11,171 feet. Cementation of the complete annulus from the casing shoe to the surface was accomplished by a three-stage cement operation.

<u>11,225 Feet to Total Depth (12,045 Feet)</u>

A 6 3/4-inch hole was drilled below the 11-inch hole at 11,225 feet. This drilling commenced on August 13 and the total depth of the hole, 12,045 feet, was reached on September 10, 1961.

Fifteen net drilling days were consumed in drilling and coring this 820-foot interval. This represents an average penetration rate of 55 feet per day.

Eight cores were taken in this interval. The lowermost core confirmed that the well had reached fractured Pre-Cambrian granite. Three drill stem tests were also run.

At a depth of 11,985 feet, an Induction-Electric log, Sonic log, Microcaliper log and Temperature log were run.

Two occurrences of lost circulation were experienced in drilling this final section. Both occurred below the top of the Pre-Cambrian rocks at 11,950 feet. From this it was interpreted that there were fractures in the Pre-Cambrian granite and a preliminary injection test into the open hole section below the 8 5/8-inch casing was attempted. This was not successful, primarily due to bridging over of the hole at numerous points.

Following the injection test attempt, an additional 60 feet of hole were drilled and cored to the total depth of the well at 12,045 feet.

A 5 1/2-inch liner was cemented at 11,975 feet. The top of the liner extends into the 8 5/8-inch casing to a depth of 11,007 feet.

Completion Activities

After cementing the 5 1/2-inch liner on September 16 the hole was cleaned out to total depth, and an injection into the interval 11,975-12,045 feet was made with the rig pumps using potable city of Denver water.

Additionally, a radioactivity log was run. The 4 1/2-inch drill pipe string was used in conjunction with airlifting equipment in the attempt to obtain a representative sample of formation fluid and reservoir pressure data. After recovering approximately 2,400 barrels of fluid the production rate dropped below the economic limit for air lift operations, and it was decided to install conventional pumping equipment. Formation fluid samples are important from the standpoint of compatability studies with respect to the fluid to be injected into the reservoir.

After the drilling rig moved off the location, a pulling unit was moved in and 2 7/8-inch tubing, pump and rods were installed. Pumping operations were conducted from October 10 to November 27. During this period approximately 2,900 barrels of fluid were produced from the well.

From the air lift and pumping operations, an approximate total of 5,300 barrels of fluid were produced. Although the plots of laboratory analyses did not show the assymptotic condition indicative of uncontaminated formation fluid, the production rates had declined below practical limits and the pumping operationswas terminated.

The pump, rods and 2 7/8-inch tubing were removed and the completion wellhead assembly was installed on November 30, 1961. The casing and hole details of the completed well are shown in Figure 7. The final wellhead assembly is detailed in Figure 8.

PHYSICAL OPERATIONS (CON'T)

EQUIPMENT

Drilling Rig

Loffland Brothers Company Rig No. 7, an Ideco PR-1050 14,000 foot rig was utilized in the drilling of the Rocky Mountain Arsenal Pressure Injection Disposal Well. Descriptive details of this drilling rig are presented in Table 3.

Major items of equipment are the rig power, pumps, drill string, and derrick. Three diesel engines provided 1,350 horsepower and a D-700 and a D-500 mud pump capable of delivering pressures of 2,727 psi and 2,350 psi with 5 1/2-inch and 5-inch liners respectively were used. The drill string assembly consisted of 4 1/2-inch Grade E drill pipe with 21 seven-inch and 14 eight-inch drill collars. The derrick was a 142-foot cantilever type mast rated at 900,000 pounds capacity. It is of interest that the permissible height of the derrick was regulated by the Civil Aeronautics Authority due to the proximity of the location to Denver's Stapleton Airfield. The regulations also required a flashing red identification beacon on the top of the mast.

Location Facilities

Field office facilities were provided by E. A. Polumbus, Jr., and Associates, Inc. A prefabricated building was installed as an office for the representative of the Corps of Engineers and the Chemical Corps.

This building was also used as a display area for well progress charts and core and ditch sample displays. It was equipped with telephone services through the Rocky Mountain Arsenal exchange. A mobile trailerhouse was used by E. A. Polumbus, Jr., and Associates, Inc., field supervisory and technical personnel as an engineering field office and a field laboratory for examination of samples by the geologists. It was also used for staff conferences held with the drilling contractor and service representatives as occasion demanded. In order to assure outside communication at all times, two telephones were installed. One was through the Arsenal exchange and the other was tied directly into the Denver telephone exchange.

Another prefabricated building was installed on location for dry storage of cores after they had been examined and boxed.

Loffland Brothers Company provided a house trailer for their toolpusher's use. A Baroid mud logging unit contained in a special trailer was located near the rig shale shaker for ready access to mud stream and shale shaker samples. For operating convenience a voice communication system from the unit to the rig floor was provided. Water for the drilling rig and other location requirements was obtained from the Rocky Mountain Arsenal system.

PENETRATION

The drilling analysis chart prepared for the Rocky Mountain Arsenal Pressure Injection Disposal Well (Figure 6) provides an accurate, unabridged record of the penetration performance and shows the interrelationships of drilling factors influencing penetration.

The principal factors influencing penetration rate include the following:

1. Lithology.
2. Hole size.
3. Drilling technique: weight on bit and rotation speed of bit.
4. Mud properties: weight, viscosity, filtrate loss, solids content.
5. Type of drilling bit.
6. Hydraulics: mud circulation rate, pump pressure and sizes of drill pipe, drill collars, bit nozzle sizes, etc.
7. Hole deviation limitations.

The foregoing factors associated with the drilling of the Arsenal well are depicted graphically and numerically on the drilling chart. The actual penetration performance is recorded by the three curves relating depth on the vertical scale and days from spud on the horizontal scale.

The penetration curve on the left, designated "rotating progress" is composed entirely of cumulative rotating on bottom time and therefore is the prime curve used in relating the various drilling factors to penetration.

The curve on the right designated "overall drilling progress" records the depth of the well at any specific lapse of time from spud. Explanatory notes and symbols placed on this curve give the important and significant events related to the drilling history.

The middle curve denoted as "net drilling progress curve" is composed of the rotating progress time, plus trip time to change bits, service the rig, drift surveys, and normal mud mixing. It is a pure drilling operations curve uninfluenced by time consumed in dealing with lost circulation, drill stem tests, electric logging surveys, fishing operations, running and cementing casing, etc. This curve is used principally in studying relative penetration performance.

Table 4 is an analysis of the drilling and coring performance in the Arsenal well prepared from the net drilling progress curve of Figure 6. The following sections discuss individually those intervals in the well which exhibited distinct drilling characteristics.

Surface to "J" Sandstone (Surface - 8, 485 feet)

The net drilling progress rate from the surface to the top of the "J" sandstone at 8, 485 feet averaged 606 feet per day. Considering the fact that a large hole was drilled (12 1/4-inch to intermediate casing point at 2, 030 feet and thereafter 11-inch hole), the greater depth at which the "J" sandstone was encountered compared with most wells in the Denver Basin and the use of mud instead of water in the upper part of the hole, this penetration rate represents an excellent performance.

During penetration of the section to the top of the "J" sandstone, drilling weights were progressively increased from 35,000 to 60,000 pounds while rotation speeds were adjusted downward from 200 rpm to 75 rpm as increased depth was attained and drilling weight added. Average hole deflection was less than 1 1/2 degrees with the exception of the interval 6, 800 to 7, 900 feet where deviation reached a maximum of 3 1/4 degrees.

Rock bits used in penetrating this section were principally OSC-3 type and averaged 530 feet per bit.

The overall drilling progress curve (Figure 6) shows that the top of the "J" sandstone was reached 29 days after spudding the well. Reference to the operational notes on this curve explains the spread of 15 days between the net and overall drilling progress curves as attributable to time devoted to hole enlargement operations for surface and intermediate

casings, running, cementing and WOC time for these casing strings, rig repairs and one brief fishing operation due to a drill pipe twist-off.

"J" Sandstone to the Top of the Lyons (8,485'-9,582')

The abrupt reduction in net drilling progress rate to 89 feet per day between the "J" sandstone and the top of the Lyons formation at 9,582 feet is characteristic of the Denver basin and denotes increasing hardness and sand content in the section.

In drilling this portion of the 11-inch hole, weights of 60,000 to 80,000 pounds and rotation speeds of 55 to 60 rpm were employed. The maximum hole deviation approximated 1 1/2 degrees. Bit types ranging from OSC-1G to W-7R were used. The drilled footage averaged 46 feet per bit, indicative of the increased hardness of this section. Mud properties were maintained in the range of 9.2 to 9.8 pounds per gallon weight, 52 to 78 seconds viscosity, and water loss, 5.5 to 8.7 cc.

The overall time from spud required to reach the top of the Lyons formation at 9,582 feet was 54 1/2 days. At this depth the spread between net and overall drilling progress curves was approximately 21 days compared with 16 days spread at the top of the "J" sandstone. This increase divergence between the two curves was the result of two drill stem tests, hole conditioning, circulating samples, rig repairs, and fishing operations for rock bit cones.

Top of the Lyons to the Top of the Fountain (9,582'-9,772')

The 190 feet of Lyons formation (9,582 to 9,772 feet) consisting principally of extremely hard quartzitic sandstone proved to be much harder in character and more difficult to penetrate than drilling histories indicated for any other wells reaching this formation in the Denver Basin. All other wells which have reached and penetrated the Lyons formation in varying amounts have been located in considerably shallower portions of the Denver Basin than the Arsenal well, the well being situated in approximately the deepest position in the synclinal trough.

One-half of the Lyons formation was cored in the Arsenal well, and the remaining half was drilled; the net drilling penetration rate averaged 28 feet per day. All hard type rock drilling bits, principally W-7R, were used for which the drilled footage averaged 15 feet per bit.

Drilling weights of about 42,000 pounds and rotation speeds of 55 to 65 rpm proved adaptable to the Lyons drilling. Mud weights averaged 9.8 pounds per gallon, viscosity 56 seconds, and water loss 7.8 cc. Hole deviation was less than one degree for this interval.

The divergence between net and overall rotating progress curves increased 5 days (21 1/2 to 26 1/2) while penetrating the Lyons section. As indicated on the overall progress curve, the drilling history of this formation was characterized by numerous lost circulation intervals associated with fractures in the hard quartzitic sand, requiring considerable time devoted to mixing mud and applying various techniques to heal the lost circulation zones.

Top of the Fountain to the Top of the Regolith (9,772'-11,880')

The 2,108 feet of Fountain section (9,772 to 11,880 feet) consisting of sandstone, shale, siltstone and arkose was cored (408 feet) and drilled (1,700 feet). Reference to the net drilling progress curve shows that this section was penetrated much more rapidly than the overlying Lyons formation. The 68 feet per day net drilling rate versus 28 feet per day represents an increase of 2.4 times in the Fountain formation.

Drilling weights of 60,000 to 65,000 pounds and rotation speeds of 50 to 65 rpm were utilized in drilling the 11-inch hole to 11,225 feet. In the 6 3/4-inch hole below this depth, drilling weights of 20,000 pounds and rotation speeds of 40 to 50 rpm were adopted. Hole deviation was permitted to progressively increase from about one degree at 10,000 feet to a maximum of 7 degrees at 11,600 feet.

While penetrating the Fountain, mud weight varied from 8.7 to 9.7 pounds per gallon, viscosity 40 to 117 seconds, and water loss 5.7 to 9.8 cc.

Drilling bit types included W-7 and W-7R rock bits and RG-2BJ insert bits. The average footage for the rock bits was 39 feet per bit or 2.6 times the footage obtained in the Lyons drilling. The RG-2BJ insert bits averaged 51 feet per bit in the Fountain formation.

The overall drilling progress curve indicates that approximately 100 days were utilized in the various operations required to achieve penetration of the Fountain section. The spread between net and overall

drilling progress curves was increased by 55 1/2 days while penetrating the Fountain formation.

Actual time drilling and coring (including reaming the core hole) in the Fountain utilized 24.8 and 19.4 days, respectively. The remaining 55.8 days were devoted to the following principal operations as denoted on the overall curve: mixing mud and healing lost circulation in the several fractured sections; running electric logs; drill stem testing; running and cementing 8 5/8-inch casing; WOC; repairing rig; fishing for rock bit cones; and reaming out keyseat within the interval 6,800 to 7,800 feet.

Top of the Regolith to Total Depth (11,880'-12,045')

The 165-foot interval from the top of the Regolith to total depth (11,880 to 12,045 feet) consisting of shale, quartzite, conglomerate, dolomite, and pre-Cambrian granite gneiss was penetrated in three net drilling days. The drilled portion (143 feet) averaged 71.5 feet per day, and the 6 3/4-inch RG-1J insert type bits obtained 49 feet per bit. Drilling weights of 20,000 pounds and 40 to 50 rpm were employed. Mud properties were 9.0 pounds per gallon weight, 43 seconds viscosity, and water loss 5.8 cc.

The overall drilling progress time devoted to this interval was 10 days which completed the operations to total depth of 12,045 feet, an elapsed time to 185 days from spud. This last period included, in addition to drilling and coring, time for running electric logs, drill stem testing, mixing mud and healing lost circulation in the fractured granite interval.

Hydraulics I ·ogram

A je ·it program was not utilized in connection with the rock bit drilling du· · the high mud circulation rates and pump pressures that would be ·quired in the 11-inch hole below 4, 000 foot depth. High penetration ra ·s obtainable with a conventional rock bit program from surface to 4, 000 feet did not warrant jet bits in this portion of the hole. Influencing factors were the extra time required to change pump liners and the additional cost of jet bits.

Coring Penetration

Reference to the drilling and coring statistics presented in Table 4 shows the following analysis of coring penetration characteristics in the Arsenal well.

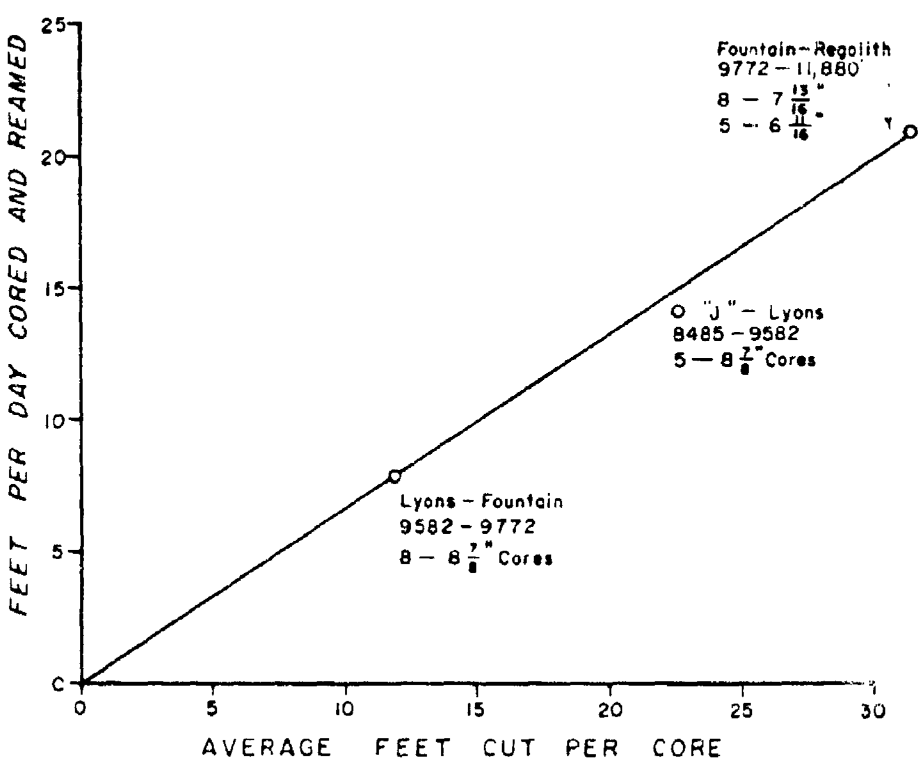
The five 8 7/8-inch diamond cores in the "J" sandstone to the Lyons interval averaged 22. 8 feet cut per core for an average penetration rate of 14. 3 feet per day including coring time plus time to ream core hole to full gauge 11-inch hole. Within the same section, drilling penetration time was 6. 2 times faster.

Within the Lyons to the Fountain section, eight 8 7/8-inch cores averaged 12. 0 feet cut per core at the average rate of 7. 8 feet per day coring and reaming core hole. Drilling was 3. 6 times faster than coring the Lyons formation.

There were thirteen 7 13/16-inch and 6 11/16-inch cores cut in the Fountain formation for an average length of 31.4 feet, and an average of 21.0 feet per day coring and reaming time. Drilling proved to be 3.3 times faster than coring.

The two cores cut in the interval from the top of the Regolith to total depth averaged 11 feet in length at the average rate of 22.0 feet per day coring only.

The following graph shows the relationship existing between average feet cut per core and feet per day cored and reamed in the Arsenal well.



The fractured intervals cored in the Lyons and Fountain sections caused wedging in the core barrel and limited the length of many cores cut in these formations. Also, lost circulation and the presence of extremely hard quartzitic pieces rolling under the diamond coring head caused "grooving" of the head which limited the length of some cores.

It is indicated from the above graphical relationship that had it been possible to cut average length 50-foot cores, the coring and reaming rate should have approximated 33 feet per day. Based on this figure, the coring and reaming time for 639 feet cut would approximate 20 days rather than the 40.5 days actually required.

Consideration was given in designing the coring program to using 11-inch diamond coring heads to avoid the time and expense of opening up a smaller sized core hole. Equating the cost of the larger diamond coring heads, the relative penetration rates and footage, reaming time, and the added problem of stabilizing the coring assembly in the 11-inch hole, the full hole 11-inch coring program could not be justified.

HOLE DEVIATION

With the exception of one reading at 370 feet, the hole deviations in the Arsenal well from the vertical stayed within the design limits. Table 5 is a summary of the deviation survey readings taken during the drilling of the well. The maximum deviation of 7 degrees was encountered at 11,600 feet.

KEYSEATING

As the well approached the depth of 11,225 feet, a tight hole condition developed in the 7,000 foot to 7,800 foot interval. Analysis of this interval with respect to hole deviation indicated a strong possibility that a keyseat had developed.

As shown in Table 5 there is a bend or "dogleg" in the hole between 6,700 feet and 8,100 feet from one degree at the top and bottom of the interval to a maximum of 3 1/4 degrees near the middle of the interval. This is portrayed graphically in Figure 6.

This nature of bend and more especially the rate of change in deviation is within the acceptable limits established in the drilling industry. However, in this case, the prolonged exposure of the dogleg to the abrading action of the drill pipe resulted in a groove being worn in the side of the hole somewhere in the interval of the dogleg. The keyseat trouble was

first manifested while drilling near 11,200 feet. This was approximately 110 days after the keyseat interval was drilled.

The usual remedial procedure of running a keyseat wiper and string reamers was adopted. However, the severity of the keyseat problem coupled with the acute lost circulation, and a desire to protect the possible injection reservoirs penetrated above the 11,225 foot depth led to a decision to alter the basic program and set the 8 5/8-inch casing at approximately 11,200 feet rather than 11,400 feet. This decision was reached in a joint meeting of representatives of the United States Army Corps of Engineers, the United States Army Chemical Corps, E. A. Polumbus, Jr., and Associates, Inc., and Loffland Brothers Company representatives.

DRILLING FLUID

The drilling mud program employed on the Rocky Mountain Arsenal Pressure Injection Disposal Well was based on the following considerations:

1. The anticipated Pierre shale section from 1,500 feet to 7,800 feet required the use of a drilling fluid which would provide maximum hole protection and minimum shale swelling over the long period that this section would be exposed.

2. The drilling fluid must provide protection to any potential injection reservoir interval.

3. The drilling fluid must be fairly simple to maintain and provide suitable temperature stability.

4. The drilling fluid should provide for maximum penetration rate and bit performance and still furnish suitable rheological properties.

In order to select a drilling fluid which would satisfy all these requirements, conferences were held with Baroid personnel, and the following mud program was established as offering the best compromise for all the properties desired.

A summary of the mud properties during the drilling operations is included in Table 6 and the following table summarizes the drilling mud program employed on the Arsenal well.

Depth	Weight	Viscosity	Water Loss	Type Mud
0 feet - 2,000 feet	9.0	54	4.4	Gel-chemical
2,000 feet - 7,450 feet	9.5	35	7.5	Low solids driscose-condet
7,450 feet - 9,500 feet	10.0	60- 80	5-7	Gyp Q-Broxin emulsion
9,500 feet - 11,225 feet	9.5	60-100	5-7	Gyp Q-Broxin
11,225 feet - Total Depth	8.5-9.0	35- 45	5-7	Low solids driscose

Constant supervision of the mud program was maintained by Baroid mud logging personnel and E. A. Polumbus, Jr., and Associates, Inc. engineers on a 24-hour per day basis.

0-2,000 Feet

The drilling fluid used in this interval consisted of a bentonite carboxy methyl-cellulose mud with caustic and tannex used as a dispersing agent. The average properties of this system were: weight, 9.0 #/gal.; funnel viscosity, 54 seconds; centipoise viscosity, 26; water loss, 4.4 ccs.; pH, 10.5; chlorides, 300 ppm. This fluid was used until 13 3/8-inch casing was set.

2,000 Feet to 7,450 Feet

Below the intermediate casing string, the drilling mud was converted to a low solids carboxy methyl cellulose mud with condet, a surfactant type material, added to accelerate settling of the drill cuttings and add lubricity to the drilling fluid. Characteristic properties of this type fluid were as follows: weight, 9.4 to 9.5 #/gal.; funnel viscosity, 31 to 38 seconds; plastic viscosity, 4 to 10 centipoises; yield point 0 to 2 grams/100 centimeters^2. Due to the very low rheological properties exhibited by this type fluid, the suspending properties were relatively low and some fill-up after trips was expected, and did occur. Past experience with this type drilling fluid indicated that some sacrifice in trip time due to the necessity of cleaning out to bottom must be made in order to achieve the benefits of increased penetration rates and bit footages which may be obtained with this type mud system.

7,450 Feet to 11,225 Feet

Past experience in the Denver-Julesburg Basin indicated that the Niobrara Formation, which contained some anhydrite but was primarily a shale section, was quite susceptible to the swelling of the formation clays when in contact with fresh water. The drilling fluid was therefore converted to a Gyp-Q-Broxin mud at a depth of 7,450 feet in order to adequately condition the hole prior to drilling the Niobrara. Additionally, 25,000 to 30,000 parts per million sodium chloride were added to the mud at this time in order to condition the mud filtrate to more nearly approximate formation water and thereby help reduce filtrate damage to the formation. In order to offset the increase in weight from the salt addition, 5 to 10 percent diesel oil was also added to the mud at this time.

The average properties of the mud before and after conversion to the gyp-base mud were as follows:

Mud Properties		Before Conversion CMC Mud Low Solids Condet	After Conversion Gyp Q-Broxin
Weight	#/gal.	9.3 - 9.5	9.5 - 10.0
Viscosity	seconds	30.0 - 0.35	60 - 90
Viscosity	centipoises	18	36
Initial gel	grams	0	3
10' gel	grams	0	25
API Filtrate	ml	7.0	4 - 7
Filter cake thickness	inches	1/32	2/32
Plastic Viscosity	centipoises	5 - 10	20
Yield Point	$gm/100\ cm^2$	0 - 2	12
pH		8 - 9	8 - 9
Salt	ppm	850	20,000
Calcium	ppm	-	1,200

The properties listed for the gyp-base mud were fairly constant to a depth of approximately 9, 596 feet at which time lost circulation occurred. Additions of salt to the mud were discontinued after the lost circulation was experienced in order to avoid corresponding weight increases. The mud weight was reduced and maintained between 9.1 #/gal. and 9.5 #/gal. until pipe was positioned at 11, 171 feet.

Lost circulation material concentration was maintained between 10 percent and 30 percent during the periods of lost returns.

The Gyp-Q-Broxin mud was used to a total depth of 11, 225 feet at which time casing was run and further drilling was conducted in a 6 3/4-inch hole.

11, 225 Feet to Total Depth

In order to provide the least expensive mud system and still afford adequate hole protection for drilling in the 6 3/4-inch hole, the drilling fluid was converted to a low solids fresh water driscose mud with the following properties; weight, 8.5 to 9.0 #/gal.; funnel viscosity 35 to 45 seconds, plastic viscosity, 15 centipoises; yield, 7. Approximately 1,000 barrels of this mud were lost during the course of drilling from 11,225 feet to 12,045 feet.

Lost Circulation

The lost circulation experienced during the course of drilling the Arsenal well is indicated on the overall drilling progress curve in Figure 6.

Details of quantities lost and depth of occurrence are presented in the following tabulation:

Well Depth	Barrels Lost	Well Depth	Barrels Lost
9,596	150	10,055	150
9,607	20	10,061	500
9,675	536	10,110	717
9,705	10	10,120	450
9,750	97	10,153	653
9,777	150	10,210	70
9,810	800	10,250	114
9,960	40	10,563	600
9,962	80	10,573	530
9,968	100	10,610	730
10,013	15	11,080	1350
10,047	200	11,985	1030
		Total	9092

The depths represent the position of the bit at the time lost circulation occurred and do not necessarily indicate the point at which fluid was lost.

Experiments conducted as soon as lost circulation became an apparent problem showed that spotting "pills" of lost circulation material on bottom when new fractures were exposed by the drill or core bit, and allowing this to set for a maximum period of 12 hours, generally remedied complete loss of circulation at that particular depth. In the case of partial loss of circulation, a maximum rate of mud loss was calculated above which the aforementioned cure was the most economical solution.

Other considerations connected with the drilling operation limited the use of other techniques in combatting lost circulation. For example,

the use of high concentrations of lost circulation material in the mud system necessary for plugging fractures could result in plugging the perforated anchor while conducting drill stem tests and thereby restricting the use of the test data. In like manner, the circulation passages through the core barrel can only tolerate a certain percentage of lost circulation material (25 to 30 percent maximum by volume) before prohibitive pressure drops through the core barrel or possible plugging of the core barrel occurs.

CORING

Summary

In the Rocky Mountain Arsenal Pressure Injection Disposal Well a total of 639 feet of section was cored with a recovery of 575 feet, representing 90 percent. A summary of the depths and recoveries for the 28 cores is presented in Table 7 .

The program design anticipated cutting 50 foot or longer cores on each coring run. However, due to extensive fracturing encountered, it was possible only in five cases to cut an interval of 40 feet or greater. The minimum cut only two feet.

Equipment

The special equipment used in the coring operation is summarized in Table 8 . For the major portion of the coring, the mechanical assembly consisted of a diamond corehead, a 50-foot core barrel, a set of safety jars, drill collars and the drill pipe. A 30-foot kelly extension was utilized after core No. 3 in order to eliminate drill pipe connections during the cutting of a core. This eliminated the possibility of junk falling under the diamond core head during the operation of making the connection.

On one coring run, No. 22, the core barrel was lengthened to accommodate a 75-foot core. On this run a total of 64 feet was cut.

Cores Nos. 25 and 26 were cut with a Bowen junk basket. This tool, pictured in Figure 9, is primarily a fishing tool for recovery of junk. Since it utilizes a coring principal, there is an occasional recovery of the formation rock. In such cases in the Arsenal well the recovery has been considered as a core run.

Runs Nos. 1 through 21 cut 4 3/8-inch diameter cores. In the lower portion of the hole, after setting the 8 5/8-inch casing, 3 1/2-inch diameter regular cores were cut. The cores recovered from the junk basket runs were 4 13/16-inch diameter.

Problems

The decision to core a rathole and ream the cored rathole before drilling ahead was primarily influenced by economic considerations. A full size corehead for the 11-inch hole would have cost approximately 75 percent more than an 8 1/2-inch corehead, and the expected life would be the same or less than that of the smaller head. Furthermore, the overall penetration rate including the time required to ream the rathole would be the same for the 8 1/2-inch or 11-inch coreheads. Additional anticipated difficulties in stabilizing the 11-inch corehead with the drill collars and the resultant undue wear also influenced the decision to rathole core.

The extreme hardness of the rock in the "J" sandstone, Dakota sandstone, Lyons formation and Fountain formation resulted in abnormal

wear and breakage of the teeth or knobs of the drilling bits. Since diamond coreheads are particularly susceptible to damage from loose metal in the hole, precautionary measures to remove the junk from the bottom of the hole were necessary. To remove such junk, extra trips running junk baskets and/or magnets were frequently made prior to coring.

In cutting core No. 3 the corehead was grooved either by loose metal in the hole or pyrite materials from the formation. The earlier procedure in coring had necessitated picking up the core barrel to make a connection. In doing this it is possible for junk or pyrites that had been held in the annulus or on the ledge of the rathole to fall to the bottom while the connection was being made. To eliminate this hazard a 30-foot kelly extension was obtained. Through its use, it was then possible to cut a full 50-foot core without lifting the corehead off the bottom of the hole.

Even though the precautionary measures described above were followed, the second corehead was grooved in cutting core No. 5 in the Dakota sandstone. This influenced the decision to forego further coring until the Lyons formation was reached. This decision was also greatly influenced by the lack of favorable indications in cores Nos. 1 through 5.

From core No. 7 it was determined that there was fracturing in the Lyons formation. This was observed in subsequent cores and evidenced by the short intervals cut in the core runs.

In a fractured formation, especially where vertical fractures are encountered, a slight slippage of the core along the fracture plane can cause the core to jam within the barrel. With a core jammed in the barrel, excessive wear on the mechanical components of the barrel can result in bearing and other mechanical failures.

The usual indication of a jammed barrel is a sharp decrease in penetration rate or a complete halt in the penetration. The short core intervals through the Lyons formation and into the Fountain formation were frequently directly attributable to such jamming.

After entering the Lyons formation core No. 6 was cut at a depth of 9,614 feet. After cutting 10 feet, circulation was lost and the coring was stopped. There was no recovery from this core.

Lost circulation difficulties continued to the total depth of the hole. Frequently the losses occurred while coring and the operation had to be suspended.

With a long core barrel of a greater diameter than the drill pipe or collars there is always a greater hazard of sticking than with a bit. In addition, the circulation channels through a core barrel offer restrictions not present with a normal drill string and bit.

Thus, whenever a hazardous condition such as lost circulation occurs while coring, an accepted practice is to pull the core barrel from the hole and conduct remedial operations with the drill string and bit.

Thus, there were three principal problems encountered in the coring operations. These were:

1. Damage to diamond coreheads from the hard formation or from junk metal in the hole. Pyrites from the formation, especially in the "J", Dakota, and Lakota sandstones, could also have contributed to this type of damage.

2. Jamming of the core in the core barrel resulting from the fractured formation.

3. Lost circulation during coring with the consequent need to suspend coring.

DRILL STEM TESTS

Summary

The original drill stem test program was designed to evaluate any intervals indicated by cores to be of interest. When a change in the coring program was necessitated, a corresponding change in the drill stem testing program was made. Basically, the change resulted in testing long intervals to give approximately full coverage of the formation rather than testing selected short intervals.

In all, fourteen formation tests were attempted. Thirteen of these used conventional drill stem test tools. One attempt was made using a wireline test tool. Details of the tests and the results are shown in Tables 9 through 22. Ten of these tests were mechanically successful. The wireline test tool plugged with lost circulation material and in the remaining three drill stem tests the packer did not isolate the zone to be tested due to the fractured formation.

Drill stem test No. 14, which tested the 11,171 foot to 11,185 foot interval of the well, recovered 5,400 feet of salt water in addition to the water cushion used in the test. This salt water showed a total chloride content of 46,400 ppm which may not represent a true formation value due to contamination. Fluid recoveries in the remaining tests consisted of drilling mud or contaminated fluids.

The following tabulation shows the intervals which were tested. These are also portrayed in Figure 10.

DRILL STEM TESTS

Test No.	Depths	Formation
1	8,482- 8,556	"J" Sandstone
2	8,628- 8,821	Dakota-Lakota Morrison
3	9,662	Lyons
4	9,845-10,016	Fountain
5	9,836-10,016	Fountain
6	9,862-10,057	Fountain
7	10,076-10,317	Fountain
8	10,137-10,339	Fountain
9	10,336-10,542	Fountain
10	10,517-10,729	Fountain
11	10,755-10,962	Fountain
12	11,096-11,439 (Csg. shoe at 11,171)	Fountain
13	9,660-11,985 (Csg. shoe at 11,171)	Fountain, Regolith, Pre-Pennsylvanian, Pre-Cambrian
14	11,020-11,985 (Csg. shoe at 11,171)	Fountain, Regolith, Pre-Pennsylvanian, Pre-Cambrian

Problems

The two tests run prior to reaching the top of the Lyons Formation presented no particular problems. In test No. 1 the packer failed near the end of the final shut-in period, but this is not uncommon.

Some difficulty in drill stem testing the Lyons formation had been anticipated. Testing of Lyons sandstones in other wells in the area had shown that the sandstones have a tendency to produce fine sand into the wellbore during tests. The sand can pack around the test tool or tail pipe and cause sticking, thus resulting in a fishing operation.

During the operation of cutting core No. 6, the first core cut in the Lyons formation, lost circulation was experienced and no core recovery was obtained. Core No. 7, cut 2 feet below core No. 6, recovered hard quartzitic sandstone with many vertical fractures.

Thus, with the direct confirmation of fracturing from the cores another hazard to drill stem testing was established. If the packer on the drill stem test tool should be set in a zone of open fractures the fluid in the annulus above the packer could easily bypass the packer into the interval being tested. In addition to invalidating the test, these bypassing fluids create an increased hazard in that they might carry solid material such as sand or lost circulation material and deposit this around the test tool, resulting in sticking of the tool.

After consideration of these various hazards and the risks involved in the various alternative methods of testing versus the data to be obtained it was decided to forego any drill stem testing in the Lyons formation. Any interpretation would have to be made from the cores and samples obtainable and the logs. More definitive evaluation could be made after cementing 8 5/8-inch casing.

After penetration into the Lyons formation, mud losses and spot cores indicated the presence of fractures in this section. Since the Fountain formation was not known to produce sand during tests, it was felt that this reduced risk would warrant resumption of the drill stem testing program.

This modified program provided for testing long intervals to effect as complete coverage of the remaining section as possible.

Tests numbers 4, 5, and 7 were not successful due to packer failures. In these cases it is interpreted that fluids bypassed the packers through fractures in the Fountain formation.

FORMATION LOGGING

Ditch Samples

A program of catching, washing, examining, describing, and preserving ditch samples taken at 10 foot or lesser intervals were followed in the drilling of the well. Samples at shorter intervals were caught whenever required by the geologist on the well. The description of these samples is included in the Sample Log in Volume III of this report.

In all, three sets of samples were prepared. One set was sent to the United States Geological Survey, Ground Water Division, Denver, Colorado. Another was furnished to the State of Colorado Oil and Gas Conservation Commission. With the permission of the United States Army Corps of Engineers, the third set was sent to American Stratigraphic Co., Denver, Colorado, a commercial sample library service. This set is readily available for public use.

In addition to these samples, the personnel of the Baroid Mud Logging unit caught and examined ditch samples at two foot or lesser intervals in the section of the well logged by this equipment. The final "Baroid ppm Log" is included in Volume III of this report.

Core Samples

All of the core material recovered was examined and described immediately after recovery and samples for core analysis were selected.

In general one sample from every foot of clastic material was analyzed. The core descriptions are included in Table 2 and in the Sample Log in Volume III. Core analysis results are presented in the log portion of Volume III and a portion are shown in Table 23.

Color photographs were taken of many of the cores, particularly those showing fractures, by the resident geologist of the Corps of Engineers.

After being described the cores were labeled, boxed, and stored in a special shed on the location. After the completion of the well, the core samples are to be stored with the United States Geological Survey, Ground Water Division in Denver, Colorado.

Chips were taken from all cores and were included with the three sets of ditch samples. The distribution of these is shown under Ditch-Samples.

Mud Logging

A Baroid Mud Logging Unit was employed on the well from the time of drilling out from under the 13 3/8-inch casing until the completion of the final drill stem test. The "Baroid ppm Log" of the interval from 2,036 feet to 11,985 feet is included under "Logs" in Volume III.

This log presents in graphical form the results of the various analyses and examinations made in the mud logging unit. The following are included:

1. A continuous record of the drilling and coring rate.

2. A graphical plot of the lithology and a description of the rocks penetrated. These are prepared from the ditch samples caught at two foot intervals.

3. Recordings of the hydrocarbons present in the mud and cuttings.

4. Recordings of the properties of the drilling mud.

The Baroid Well Logging Service also provided an on-location core analysis, a copy of which is included in Volume III. In order to substantiate the core analysis data determined by the logging unit, 52 core samples were randomly selected and analyzed by an independent core laboratory. The results of this check revealed essential agreement between the two evaluations. (Table 23.)

Examination of the Baroid Mud Logging Report indicates the absence of any significant hydrocarbon zones. A gas kick of 30 units was indicated through the Niobrara section. This is quite typical of the Niobrara shale throughout the Denver-Julesburg Basin. Additional large gas kicks noticed at 7,700 feet were due to the addition of diesel oil to the drilling fluid. Off-scale deflections were recorded at various other intervals after roundtrips out of the hole with the drill string. This phenomenon was the result of entrained gas in the mud system derived from the gas shows in the Niobrara.

Electric Logging

Summary

An Induction-Electric log and a Gamma Ray Neutron log were taken through the major portion of the Arsenal well. Less complete coverage was made with the Sonic log, Microlog, and Temperature log. Copies of all logs taken in the well are included in Volume III. Table 24 is a tabulation of the various logs, the dates run, and other pertinent data.

Problems

An Induction-Electric log and Microlog were run before setting the 13 3/8-inch casing. A 12 1/2-inch hole was drilled to 2,030 feet and logging was attempted. On the first attempt the sonde encountered a bridge or obstruction at 800 feet. A cleanout trip was made with the bit. Again bridges were encountered. This process was repeated until on the fourth attempt the sondes went to bottom and the logs were run.

Since the hole was to be reamed to 17 1/2 inches the possibility of reaming the hole and then logging was considered during the period of these difficulties. However, the quality of logs run in large diameter holes is frequently very poor. Thus, it was decided to continue the cleanout runs in order to take the logs in the smaller 12 1/2-inch hole.

The logging runs at a drillers depth of 9,729 feet presented no problems.

After the keyseat difficulties developed upon reaching a depth of 11,225 feet, it was decided to log the hole and run the 8 5/8-inch casing. Therefore, an Induction-Electric log and Sonic log were taken.

The Sonic log sonde encountered some bridges going into the hole but it was worked to bottom. Three tight spots were encountered coming out of the hole and it was found that one of the rubber coverings on the sonde had been lost.

It had been planned to run a Caliper log in order to calculate the volume of the hole prior to cementing the casing. However, after the difficulties encountered running the Sonic log, it was decided to determine the volume by other means and the log was not run.

In the log runs at a drillers depth of 11,985 feet, the first attempt to run the Temperature log was a misrun. The second attempt was successful.

The only log taken in the interval from 11,985 to 12,045 feet was a Gamma Ray Neutron log. This was run without incident.

CASING INSTALLATION

A summary of the casing and hole program used on the Rocky Mountain Arsenal Pressure Injection Disposal Well is enclosed as Table 25. Figures 7 and 11 graphically portray the casing and hole program and the details of the casing strings. A summary of the individual casing string assem ies are as follows:

20-inch Casing

The 20-inch casing string, which was set at a depth of 135 feet in a 24-inch hole, consisted of 94 #/ft. H-40 casing with short threads and couplings and a Baker Guide Shoe. This casing string would have no severe stresses imposed and serves only to support the loosely consolidated sand and gravel near the top of the hole. Portland cement was circulated around this entire casing string back to the surface.

13 3/8-inch Casing

The following 13 3/8-inch casing string was used in the final installation. This casing string was positioned in a 17 1/2-inch hole at 2, 020 feet. This casing string was also cemented with Portland cement with its entire length being protected with this material.

This string includes a Baker Guide Shoe on the bottom and a baffle collar one joint off bottom.

	O. D.	Lbs. /ft.	Grade	Coupling	Nom. I. D.	Drift I. D.
Top	13. 375	54. 5	J-55	LT&C	12. 615	12. 459
Middle	13. 375	48. 0	H-40	LT&C	12. 559	12. 559
Bottom	13. 375	54. 5	J-55	LT&C	12. 459	12. 459

The 13 3/8-inch casing string served as a base for the blowout preventers during drilling operations and as a support for the load imposed by the 8 5/8-inch casing and the 5 1/2-inch tubing strings after completion of the well.

8 5/8-inch Casing

The shoe of this casing string was positioned at 11, 171 feet and the casing was cemented over its entire length back to the surface.

	O. D.	Lbs. /ft.	Grade	Coupling	Nom. I. D.	Drift I. D.
Top	8. 625	40. 0	N-80	Extremeline	7. 725	7. 600
Middle	8. 625	40. 0	H-80	LT&C	7. 725	7. 600
Bottom	8. 625	44. 0	N-80	LT&C	7. 625	7. 500

To position the 8 5/8-inch casing an 11-inch hole was drilled to a total depth of 11, 225 feet. Because of the complexities involved in the cementation of over 11, 000 feet of casing from shoe to surface, extensive planning and preparation was necessary. Figure 12 illustrates a typical 3-stage cementing job.

Hole Preparation

The initial operation in the completion procedure is the preparation of the hole for casing running, and placement. The condition of the hole at the time when 8 5/8-inch casing was run was: 20-inch casing cemented at 135 feet, 13 3/8-inch casing cemented at 2, 020 feet, and 11-inch hole drilled to 11, 225 feet.

The mud properties were: weight, 9. 4 ppg; viscosity, 120 seconds; plastic viscosity, 30 cp; yield, 15 gm/100 cm^2; water loss, 5 cc; lost

circulation material, 15 percent; oil, 10 percent; pH, 8.5; chlorides, 4,200 ppm; and preservative, 0.3 percent.

This mud system was circulated for a sufficient length of time to completely stabilize the bore hole.

Supervision

Prior to the undertaking of any major operation on the Rocky Mountain Arsenal well, consultation was held between representatives of the service companies involved and E. A. Polumbus, Jr., and Associates, management and consulting engineers. A number of specialized meetings were held prior to the installation of this 8 5/8-inch casing string.

From these meetings a series of instructions were printed for the field personnel. The following comments are some of the highlights from these recommendations:

1. A Halliburton engineer was on location to supervise making-up of the bottom float equipment.
2. A Youngstown engineer was present to inspect the make-up of the joints.
3. The pipe was strapped twice while lying on the pipe rack so that a double check was made.
4. A catalyic agent was used on all connections in the bottom 90 feet of the assembly for the first casing joints. The pipe grade was N-80 steel and was not welded because of possible crystalization damage.

5. All 49 #/ft. 8 5/8-inch casing was stacked separately.

6. The threads were cleaned with a wire brush and each thread protector was in place before it was pulled up from the walk.

7. The casing was handled with extreme care when it was moved from the rack to the derrick.

8. A modified API thread lubricant, that is, one without a silicone base, was used on each joint.

9. The accuracy of the weight indicator was checked to aid in subsequent calculations.

10. All Halliburton surface lines and connections were pressure tested to 5,000 psig.

11. Since a professional crew was utilized in running casing, the danger from the standpoint of accidents was greatly reduced. As the running of the casing was to take over 20 hours, laxity on the part of the crew was one of the major problems.

The mechanical aspects of running the casing are summarized in some of the following points:

1. The makeup torque for the extremeline casing was 4,500 ft.-lbs. The makeup torque for the long-threaded and coupled casing was 4,900 ft.-lbs.

2. Fillup of the 8 5/8-inch casing was done as follows:

a. Each joint of the 8 5/8-inch casing was filled with mud during the raising of the next joint preparatory to insertion and makeup.

b. Each 10 joints the casing was completely filled.

c. When the bottom of the casing was at a depth of 8,200 feet, the filling of the casing was discontinued. The Loffland Brothers Company considered this depth to be safe as far as rig requirements were concerned. The remainder of the casing was floated in.

3. When setting the casing in the slips and picking up the casing, the slips were set as gently as possible to avoid any quick movement of casing either in setting or releasing.

4. Speed of running casing was limited to 1 foot per second to minimize pressure surges at the bottom of the hole.

Rate of Lowering

Because of the zones of lost circulation which were exposed to the well bore at the time the casing placement, extreme care had to be exercised so that pressure surges would not break down the formation and cause a loss of circulatory returns. An extensive investigation indicated that the largest surge would exist at the time of cementation provided that certain limits were adhered to in the rate of lowering the casing string. During the drilling operation it was noted that mud weights which exerted

greater than 6,300 psi bottom hole pressure would rupture the formation. Therefore, this value was utilized as the maximum permissible bottom hole pressure during the running and placement of casing.

The pressure surge calculations indicated that the maximum pressure obtained in the lowering of the casing would be below the critical value of the formation provided the lowering rate was 1 foot per second or less.

The three major forces exerted at the bottom of the hole during the running of the casing string are:

1. The piston-like movement of the casing itself.
2. The viscous drag of the mud along the sides of the casing, and
3. The inertial effects when the casing is lifted from and placed in the slips.

Casing Running

The making-up of the float shoe and collar by Halliburton engineers began at 5:50 p.m. on 2 August 1961. The bottom 90 feet of casing had its joint locking ability supplemented by a chemical catalytic compound. The casing was in position at 2:15 p.m. on 3 August 1961. The professional crew employed for this operation had made up each joint with air compressor powered tongs. These tongs had a remote gauge which indicated the foot pounds of torque applied to each individual joint of casing.

The overall casing placement operation was smooth and efficient. At one point when the shoe of the casing was set at approximately 7,500 feet, the rate of lowering was controlled completely by the weight of the casing string. That is, it took the entire weight of the existing string to pass through this interval. As was pointed out in the drilling section of this report, considerable key seat trouble was encountered in this area. After this depth had been passed by the casing shoe, very little resistance was noted.

Cementing Operation

The stage cementing collars were located in the relative position shown on Figure 11. Three separate stages of cement would be necessary to completely isolate the casing from the bore hole. The first stage cementing collar was positioned at 8,966 feet while the top stage collar was positioned at 4,507 feet.

First Stage

In view of the fractured condition of the lower portion of the hole, a gilsonite additive was blended with the cement. The bottom hole temperature of 250° F was not sufficient to be detrimental to the gilsonite slurry. The melting point of gilsonite is 385° F. Twenty-five pounds of gilsonite were blended with each sack of the pozzolanic mixture. Gilsonite is a solid asphaltene hydrocarbon which reduces slurry weight and mimimizes lost circulation by bridging the larger passages of permeability.

The slurry properties with the gilsonite additive were 12.5 ppg and a slurry yield of 1.75 cubic feet per sack.

Because of the bridging characteristics of gilsonite, the first portion of the slurry was a gilsonite-free mixture. Since the cementing operation went as planned, its position at the bottom of the cement column provided protection in the intervals where the maximum pressure from the hydrostatic head was exerted.

The cementing material in the lower stage is subjected to relatively high temperatures. Because of this condition, consideration was given to strength retrogression.

Halliburton Company studies on the strength behavior of different oilwell cements at extremely high temperatures indicate that all of the manufactured cements lose much of their strength at temperatures above 230° F.

Pozmix 140, due to its chemical nature, does not lose strength, but actually increases it at higher temperatures. It has excellent pumping characteristics and has never, to the knowledge of the Halliburton Company, flash set in any deep well. Pozmix 140 was selected as the best cementing material for this first stage operation because of minimized additive requirements and high compressive strength.

To insure adequate mixing, pumping, and displacement times, five-tenths percent of HR-4, a lignon retarder, was blended with the

cement. This concentration of HR-4 permitted over four hours for the operations to be completed.

The cement slurry weight was approximately 12.5 pgg as opposed to a 9.4 ppg mud system. This differential caused the cement to be displaced at the surface on a vacuum until the time of equalization of head pressures. Equalization time occurs when the same equivalent hydrostatic head is present in and outside the casing. During this period of rapid fall, all available pumps were utilized to displace the slurry to minimize hesitations and preclude the possibility of disassociation.

No mud acid or similar material was used ahead of this first stage of cement. At the time of cementation all zones of lost circulation were sealed off. The introduction of mud acid or similar material could disrupt this healing property and cause the loss of the cement to the formation.

Second Stage

A 50-50 pozzolanic Portland cement mixture was utilized in this stage with 6 percent bentonite added to the slurry. The properties were 7.66 gallons of water per sack in a slurry weight of 13.3 ppg. The slurry volume yield was 1.53 cubic feet per sack.

Because of the delay which was experienced between the second and third stages of the cementing operation, due to the necessity for trucking in of materials, a spearhead of 1,000 gallons of mud cleanout

acid was circulated ahead of the cement slurry. The extensive circulating time could have left a deposition of mud cake in the annulus which would have had a detrimental effect upon the second stage cement displacement.

The second stage cement was retarded with four-tenths percent HR-4 to provide adequate pumping and displacement times.

Third Stage

The upper stage of cement was a 50-50 mixture of pozzolan and Portland cement with 6 percent bentonite added. The addition of this bentonite increased the slurry volume to 1.5 cubic feet per sack and rendered a slurry weight of 13.3 ppg. No retarders were added to this mixture since adequate time was available for its pumping and displacement.

To summarize, the cementing material for the first stage was pozmix 140. This is a special h[illegible] temperature cementing material. The second and third stages were cemented with mixtures of 50-50 pozzolanic and Portland cements.

Operating Procedures

During the first stage of cementation the primary limitation of the displacement rate was the allowable surface pressure of 600 psig.

As soon as the preceding cementation was completed, the bomb was dropped opening the next stage ports.

After circulation had been established, circulation was continued until the mud properties become uniform. Before starting to place cement in stages two and three, the hook load equivalent to the weight

of pipe below the free point of the cement was slacked off. Fifty thousand pounds of residual weight was necessary to land the slips in the casing head.

To provide for adequate setting times, 24 hours was provided before any stage collars were drilled out.

Materials and Equipment

Because of the difficulty encountered in lowering the electric log sondes, a caliper log was not available for calculation of cementing volumes. A substitute method of calculation was employed by pumping down tracers and calculating an equivalent hole size from the lag time. This method provided the following volumes: for the first stage 1,030 sacks of pozmix 140 with five-tenths percent HR-4 and 410 sacks of gilsonite-pozmix 140 mixture. The second stage was cemented with 2,550 sacks of 50-50 pozmix and Portland cement with 6 percent bentonite and four-tenths percent HR-4. The top stage was cemented with 2,020 sacks of 50-50 pozmix Portland cement with 6 percent bentonite.

At the rate of displacement permissible in the first stage of the cementation, the friction losses would approximate 300 psi. The equivalent hydrostatic head exerted on the formations would be 5,700 psia. The difference between this value and the 6,300 psi permissible bottom-hole pressure would allow 600 psi surface pressure. This was the limiting value for the first stage displacement.

The validity of these assumptions was confirmed as the complete cementing job was consummated with no apparent loss of returns.

As mentioned before, the casing was in position on August 3, 1961, at 2:15 p.m. At this time the cementing head was placed on the casing string and circulation was established at 4 p.m.

The first stage cementing job began after the mud system had been equalized at 6:30 p.m., and the mixing of cement began. At 7:35 p.m. the cement had been pumped in the casing and the top plug was positioned to effect the displacement. At 9:35 p.m. the cement had been displaced without incident and the bomb was dropped to open the first stage tool. One hour later 800 psi pump pressure was applied to the casing and the stage tool opened. Circulation was established with a pump pressure of 500 psi. So that the weight below the free point could be slacked off, a minimum of 12 hours waiting on cement time was allowed to elapse.

When the fluid material immediately above the stage collar had been circulated to the surface, it contained approximately 75 barrels of cement. This would indicate that the lower stage was successfully cemented and preparation for stage two began.

Twenty-eight thousand pounds of hook load was safely slacked off since this represented the weight of casing below the top of the hardened cement.

On August 4, 1961, at 3:45 p.m. the second stage of the cementing program was inaugurated. One thousand gallons of mud acid was used as a spearhead to the cement mixture. At 3:50 p.m. cement was being pumped into the casing. At 5:25 p.m. the top plug was positioned to facilitate the displacement of the cement from inside the casing. At 6:08 p.m. the plug landed and at 6:30 p.m. the top bomb was dropped to open the upper stage tool. At 6:52 p.m. 800 psi pressure on the casing opened the upper stage tool. Circulation was maintained with a pump pressure of 300 psi. At 8 p.m. it was noticed that approximately 100 barrels of cement were circulated to the pits. This indicated a good cement job and an overlapping of cement area.

For some unexplained reason during the circulation the stage tool malfunctioned and mechanically closed itself. To complete the cementing operation, 6 holes were placed in the casing just above the stage collar at 4,501 feet.

On August 5, 1961, at 11:55 a.m. circulation was re-established with a pump pressure of 400 psi. At 12:30 p.m. 1,000 gallons of mud acid were pumped into the casing followed by the cement mixture. At 1:20 p.m. the cement was in place inside the casing and the top plug was positioned for the displacement. At 1:50 p.m. the circulatory returns were cement. At 2:05 p.m. approximately 70 barrels of cement had been circulated. At this time the pipe rams were closed and ten additional barrels of cement were pumped in an attempt to seal off the perforations.

After the completion of the cementation operations, all of the weight of the casing string was slacked off except the residual weight required to land the casing in the slips of the well head. A period of 24 hours was then allowed for the setting of the final stage of cement.

Testing

The 8 5/8-inch casing was set at a depth of 11,171 feet and cemented in three stages to the surface with 6,050 sacks of cement. Six perforations were made in the casing from 4,501 feet to 4,502 feet.

The top stage collar was drilled out after the 24-hours waiting-on-cement time had elapsed and the casing was pressured to 2,000 psi. The pressure testing of the 8 5/8-inch casing was necessary to insure that a segregation existed between the injected water and the shallow ground waters in the event that a hole in the 5 1/2-inch injection tubing developed at a later date.

On August 8, 1961, a series of tests were conducted with the rig pumps and Halliburton pumps to test the cementing job on the 8 5/8-inch casing string. Each of these tests indicated a loss of pressure and a remedial squeeze operation was necessary.

Rather than squeeze the formation with extremely high pressures an attempt was made to repair the existing cement bond. Latex cement was selected because of its good bonding characteristics with all other types of cements. A 50-sack slurry was used with nine-tenths gallons

of latex per sack of mixture. The slurry weight was 15.1 ppg, the water requirement was 5 gallons per sack, and the slurry yield of the volume was 1.25 cubic feet per sack. A pressure of 2,500 psi was used to attempt the displacement of the latex cement mixture.

Subsequent testing indicated the leak had not been repaired after suitable waiting-on-cement time. One additional squeeze operation, however, using the same volumes and cement mixtures achieved a satisfactory test.

Liner Installation

After the 8 5/8-inch casing had been set, cemented to the surface, and tested, a 6 3/4-inch hole was drilled to the existing total depth of 12,045 feet. After a series of preliminary injection tests had been conducted it was concluded that the additional investment of the liner completion would be warranted.

Because of the availability on the location of the 5 1/2-inch, 23 #/ft. N-80 extremeline tubing, it was selected as the material to be used for the liner. The bottom of the liner was to be positioned at the top of the fractured granite interval while the top of the liner would overlap into the bottom of the 8 5/8-inch casing string.

To minimize the amount of cement moving downward, a magnesium open hole bridge plug was placed at 11,985 feet with a cement plug positioned on top of this obstruction. The liner was then made up with a Baker float shoe shown on Figure 13 and a Baash-RossLiner Hanger.

Because of the high formation temperatures, the cementing material again was pozmix 140. This material was selected because of its resistance to strength retrogression at high temperatures.

The liner was run and positioned without incident. After the cement had been displaced, the packing element was withdrawn from the liner hanger and reverse circulation initiated. After the hole had been thoroughly circulated, final completion operations were commenced.

PHYSICAL OPERATIONS (CON'T)

PRELIMINARY TESTS

Two types of tests were conducted at the Rocky Mountain Arsenal Disposal well. The first injection tests to note fluid disposal susceptibility and the second was production tests to attempt to obtain a representative reservoir fluid sample.

Injection Tests

The prospective reservoir exposed from 11,975 feet to 12,045 feet was tested to evaluate, in a cursory manner, its injection possibilities. The test results were favorable enough to warrant initial completion. This phase of the completion operations will be covered thoroughly in a subsequent report entitled "Initial Fluid Injection Characteristics Pre-Cambrian Interval" to be released March 15, 1962, by this office.

Production Tests

Before the drilling rig was released, efforts were made to obtain a formation fluid sample employing air lift. A method of lift was necessary since the reservoir pressure was not sufficient to cause natural flow to the surface. The air lift method of production proved to be uneconomical because of the low rate of fluid entry into the well bore.

After the rig was removed, a beam pumping unit was installed to lift the reservoir fluid. After several days of pumping, fluid entry into the well bore again was so small that the continuation of efforts to obtain a sample seemed unwarranted.

After 1, 100 barrels of fluid, in excess of the injected volume, were recovered the chloride content was approximately 32, 000 ppm. The trend of chloride concentration was approaching the 46, 000 ppm present in the fluid from drill stem test No. 14.

PHYSICAL OPERATIONS (CON'T)

COMPLETION

The casing program employed on the Rocky Mountain Arsenal Well effectively exposed the open hole section from 11,975 feet to 12,045 feet to the well bore. After preliminary injection tests had indicated the presence of a potential reservoir through this interval, steps were taken to permanently complete the well.

Subsurface Equipment

A print of the type packer employed for the subsurface installation is shown on Figure 13. This packer is a Baker Model D, which has proven itself in many years of oilfield operation as one of the more dependable types of packing installation. This packer affects the segregation between the injected waters inside the tubing and the fresh waters in the tubing-casing annulus.

The packer was set by the use of wireline implement which provides the more positive setting mechanism. The packer was positioned just below the first stage cementing collar at 8,998 feet. The well bore was next prepared to run the 5 1/2-inch 23 #/ft. N-80 extremeline tubing for the injection path.

Tubing Installation

The bottom section of the tubing string is composed of a Baker production tube which is a perforated short length of tubing. This perforated tube has an inside diameter opening of 2 5/16 inches. This dimension is

depicted on Figure 7. The next article of installation was the seal nipple assembly. This assembly actually affects the packoff within the bore of the Baker Model D packer. Both the seal nipples and the production tube pass through or are sealed inside the packer. The tubing itself is positioned at the top of the packer.

Tubing Set-Down Weights

After the tubing had been run and positioned at the top of the Model D packer, 65,000 pounds tubing weight was slacked off to compensate for subsurface forces acting to disrupt the tubing to annular seal.

Values of necessary setdown weights were calculated taking into account three forces--two caused by changes in pressure and one by temperature variations. These forces are summarized as follows:

1. Force due to internal and external pressure changes acting on the end areas of the packer.

2. Force due to internal and external pressure changes acting on the inside or the outside walls of the tubing, causing ballooning or reverse ballooning.

3. Force due to temperature changes of the tubing.

Under the conditions of injection the force on the end areas of the packer would produce the resultant of about 7,000 pounds in a downward direction. The ballooning force, force No. 2, resultant, would be 17,000 pounds in an upward direction, and the temperature force, force No. 3,

would be 55,000 pounds in an upward direction. The net effect on the setdown weight would be a reduction of 65,000 pounds.

Since this force is equal to the setdown weight employed at the time of the installation, the tubing will be essentially in equilibrium with the overall length of the seal nipple assembly being an insurance factor for tubing annular segregation. Since these calculations were based on the wellhead surface pressure of 2,000 pounds, an additional safety factor is incorporated in the calculations.

Before the tubing was positioned and landed the final time, potable water was circulated into the annular area between the 5 1/2-inch tubing and the 8 5/8-inch casing.

Stimulation

Since a considerable amount of drilling fluid was lost in the open hole section below the 8 5/8-inch casing shoe, 3,000 gallons of mud acid were injected and produced back to cleanup the area immediately surrounding the well bore.

Well Head

The well head serves as a hanger for the casing and tubing as well as a control device at the surface to permit performance of necessary operations under various well conditions. A drawing of the well head equipment installed at the Rocky Mountain Arsenal is shown on Figure 8. The primary sections of the well head are the casing hanger, tubing spool, master valve, float tee, and lubricator valve.

Each of the casing strings requires a hanger positioned at the well head. Each of these casing strings is hung from this hanger by means of a slip and seal assembly. Since the injection pressures will be applied to the tubing spool, it must be a 3,000 pound working pressure which is an API series 900 rating.

Because of the need for running full diameter tools within the tubing, the master valve is of sufficient size to allow such tools to pass. A 6-inch series 900 full opening gate valve is the smallest valve commercially available which met this requirement.

A 6-inch by 6-inch by 4-inch series 900 studded tee is positioned above the master valve with a 4-inch outlet oriented to receive the flow line. This opening is commensurate with the diameter of the discharge lines above the injection pumps.

The small diameter gate valve above this flow line tee allows the introduction of special tools into the well bore without dismantling the well head. This valve has an inside diameter opening comparable with 2 1/2-inch tubing.

At the top of this valve, called the lubricating valve, a tapped bull plug leads to a needle valve and gauge which are provided for visual observation of the tubing pressure. All of these fittings are rated at 3,000 psi working pressure. This well head design provides for all foreseeable requirements within the 2,000 psi operating pressure anticipated.

Surface Safety Devices

With the tubing landed in the packer at the bottom end and the tubing in the slips and sealing assembly at the well head, the annular volume between the 5 1/2-inch tubing and the 8 5/8-inch casing becomes a closed chamber. If any leaks occur in this chamber, a pressure sensing device at the well head would be activated. For this reason, a continuous pressure recording device is incorporated in the well head design. By this means any anomalous pressure behavior in the annulus will be detected immediately and remedial steps can be initiated.

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DEVIATION FROM DESIGN (VI)

DEVIATION FROM DESIGN

DRILLING

The deviation of actual drilling program details and time schedule from the program and forecasts presented in the Final Design Analysis report released by E. A. Polumbus, Jr., and Associates, Inc., on July 5, 1960 is summarized in the following tabulation:

Items	Estimated	Actual	Difference
Total Depth	11,400'	12,045'	+ 645'
Number of Cores	15	28	- 13
Footage	689'	639'	- 50
Drill Stem Tests	14	14	-
Electric Log Runs	2	3	- 1
Casing Strings	3	4	+ 1

Time Analysis -Spud to Total Depth

	Days		
Net drilling time	46.67	55.30	+ 8.63
Coring and reaming core hole	30.19	40.50	-10.31
Drill Stem Testing	13.00	13.60	+ 0.60
Electric logging	1.50	4.80	- 3.30
Run, Cement, WOC and recement casing	6.00	18.20	-12.20
Lost circulation, mix mud, condition hole	7.00	31.50	-24.50
Fishing: drill pipe, bit cones, junk, etc.	0.00	8.90	+ 8.90
Contingencies including waiting on orders	5.00	5.90	+ 0.90
Rig repairs	0.00	6.30	+ 6.30
Total Days	109.36	185.00	-75.64

Reference to the DASCO drilling analysis chart (Figure 6) shows that net drilling time in the Arsenal well from surface to the top of the Lyons

at 9,582 feet was 33 days. This compares to 33 net drilling days forecast in the Final Design Report required to reach the top of the Lyons at an estimated depth of 9,746 feet.

The forecast net drilling time from the top of the Lyons to the estimated total depth of 11,400 feet was 26 days for the anticipated 1,654 feet net interval. The 1,818-foot interval penetrated in the Arsenal well from the top of the Lyons at 9,582 feet to 11,400 feet required 51.5 net drilling days. The section of this report dealing with Penetration treats of the various factors in the Arsenal well contributing to this difference of 25.5 net drilling days.

GEOLOGY

The following tabulation summarizes the estimated versus actual depths of the various geological marker tops in the Arsenal well:

Geologic Formation	Depth to Top: Estimated	Actual
Fox Hills	1,345'	1,250'
Pierre Shale	1,455'	1,480'
Hygiene Zone	5,325'	5,448'
Niobrara	7,805'	7,710'
Carlile Shale	-	8,078'
Greenhorn Limestone	-	8,120'
Granerous Shale	-	8,345'
"J" Sandstone	8,576'	8,485'
Dakota Sandstone	8,816'	8,633'
Lakota Sandstone	8,916'	8,730'
Morrison Formation	8,936'	8,786'
Lykins Formation	9,341'	8,972'
Lyons Formation	9,746'	9,582'
Fountain Formation	9,865'	9,772'
Regolith	-	11,880'
Ordovician? Cambrian?	-	11,895'
Pre-Cambrian Schist	-	11,950'
Pre-Cambrian Gneiss	11,400'	11,970'

CASING AND COMPLETION PROGRAM

The principal differences between the program originally designed and the program actually followed were the setting depth of the 8 5/8-inch casing string and the total depth of the well.

Hole conditions dictated the necessity for the premature setting of the casing while the actual depth was some 600 feet deeper than that anticipated. Because of these conditions, a liner completion was necessary to case off the interval from the top of the pre-Cambrian rocks to the bottom of the 8 5/8-inch casing.

The following table summarizes some of the main points of necessary deviation:

	Designed	Actual
Total Depth	11,400 ft. ± 300 ft.	12,045 ft.
Casing Setting Depths		
20 -inch	125 ft.	135 ft.
13 3/8-inch	2,000 ft.	2,020 ft.
8 5/8-inch	11,400 ft.	11,171 ft.
5 1/2-inch	Not Required	11,975 ft. (liner)
Packer Setting Depth	10,000 ft.	9,000 ft. (approx.)
Tubing Required	10,000 ft. (approx.)	9,000 ft. (approx.)
Casing for Liner		
5 1/2-inch	None Required	1,000 ft. (approx.)
Perforating	Jets or Bullets	None Required

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RESUME OF ORGANIZATIONAL FUNCTIONS (VII)

RESUME OF ORGANIZATIONAL FUNCTIONS

The design and drilling of the Rocky Mountain Arsenal Pressure Injection Disposal Well was assigned to the U. S. Army Corps of Engineers, Omaha District, by the U. S. Army Chemical Corps. The Corps of Engineers in turn engaged the firm of E. A. Polumbus, Jr., and Associates, Inc., to design the well, supervise the drilling and completion, provide the necessary engineering and geological services, and manage the project. These services were provided for under an Architect-Engineer type contract (contract No. DA-25-066-eng-6033). The design of the treating plant facilities was assigned to A. J. Ryan and Associates under a separate contract.

Corps of Engineers

Colonel H. G. Woodbury, Jr., District Engineer, U. S. Army Corps of Engineers, Omaha District, appointed Lt. Colonel J. M. Frassrand as Contracting Officer for contract DA-6033. Colonel J. J. Haley replaced Lt. Colonel Frassrand in October, 1961. Mr. Ralph E. Rader, Chief Military Design Branch, served as Contracting Officer's Representative throughout the term of the contract.

Other Corps of Engineers supervisory personnel who were directly or closely associated with the project were Mr. J. Ackerman and Mr. Gordon Haugse. Mr. Ackerman was aggressively involved during the initial phases of the negotiations between the Corps of Engineers and the

Polumbus firm. He also was active in later critical phases of an administrative nature. Mr. Haugse functioned throughout the term of the contract in a liaison capacity expediting necessary contacts between Polumbus personnel and the Corps of Engineers.

The Corps of Engineers' field representative was Mr. J. Zeltinger. He was assigned to the well site as a geological observer.

Chemical Corps

Although not directly involved in the design or construction phase of the project, the Rocky Mountain Arsenal administrative personnel contributed appreciably to the efficient functioning of the operation. Through their co-operative efforts, Colonel William J. Allen, Jr., Commanding Officer until his retirement, September 30, 1961, his successor, Colonel Charles H. McNary, and Mr. George F. Donnelly, Chief, Engineering Division, effected a well co-ordinated relationship between the Arsenal Complex and the drilling operation.

Mr. John O. Neighbours, Jr., was assigned to the project as an engineering observer on the well site. His familiarity with governmental procedures and visiting government personnel coupled with the knowledge he acquired during the progress of the operation was of considerable aid to the project management.

E. A. Polumbus, Jr., and Associates, Inc.

Mr. E. A. Polumbus, Jr., president of the consulting petroleum engineering firm, appointed Mr. O. E. Mechem as project manager for all engineering and operations work done under contract DA-6033. Prior to this contract Mr. E. O. Gregory of the Polumbus firm was in charge of the preliminary design work conducted under the earlier contract, DA-5969. Mr. D. M. Love was appointed to handle the comptroller aspects of the contract which involved matters of finance, accounting, and bookkeeping.

The design, planning, and contracting phases of the contract were handled by various specialists in the Polumbus firm, with the details being handled for the most part by Mr. C. E. Haskett and Mr. Al Samuels. Mr. Mechem personally conducted conferences and negotiations regarding drilling specifications and design of a drilling contract. This effort culminated in a contract (No. 6724) being awarded to the Loffland Brothers Company for the drilling of the well. Mr. Henry Sikso served as Contracting Officer's Representative for the Loffland contract. Inasmuch as E. A. Polumbus, Jr., and Associates, Inc., under contract No. 6033 was authorized to manage the drilling operation under contract No. 6724, a close association developed in the co-ordinated handling of the two contracts. Not only were the physical operations conducted under the direction of the Polumbus firm, but the accounting of expenditures for both contracts was routed through the Polumbus' office comptroller section.

Mr. Mechem's duties as project manager for E. A. Polumbus, Jr., and Associates covered all phases of the drilling and completion of the well. He was required to be familiar with all developments on the well, and to be available for conferences at the well site as well as in the various business offices at all times.

The contract called for 24-hour engineering supervision at the well site. Engineers from the Polumbus firm were assigned to regular and relief 12-hour shifts. Mr. Al Samuels was designated as Project Drilling Engineer on the well site. He maintained constant contact with the well either by actually working at the site during one of the 12-hour shifts or through telephone contact with the engineers on duty.

Mr. L. J. Scopel was the Project Geologist and was responsible for all geological aspects of the operation. He was available on 24-hour call throughout the drilling of the well. The Baroid mud logging facilities included operators on the unit on a 24-hour basis. This personnel was under the supervision of the Project Geologist.

Mr. J. H. Garrett was the Project Completion Engineer and directly supervised the completion activities, including injection testing, procurement of formation water samples and the final setting of the well head.

Various other members of the Polumbus staff followed specific phases of the operation and were available for consultation or field

operation in their specialities. Among e were Mr. B. A. Lear as Project Testing Engineer, and Mr. D. A. R land as Project Reservoir Engineer.

Throughout all phases the Project Manager was informed daily of the progress and developments on the well. He was also notified of any special developments at the time of occurrence. This information was relayed, daily, to the Corps of Engineers in Omaha. Whenever a question arose or technical and/or managerial advice were required, the entire staff of the Polumbus firm as well as specialists from the drilling contractor and oilfield service companies were available for consultation. Conferences were held in the Polumbus Denver offices and at the field office for all major decisions.

Following is a list of technical and managerial personnel in the Polumbus organization that were associated directly with the drilling and completion of the Rocky Mountain Arsenal Pressure Injection Disposal Well:

Drilling, Completion, Testing, and Management

E. A. Polumbus, Jr.	President and General Manager
O. E. Mechem	Project Manager
D. M. Love	Comptroller
A. Samuels	Project Engineer-Drilling
J. H. Garrett, Jr.	Project Engineer-Completion
D. A. Rowland	Project Engineer-Reservoir
B. A. Lear	Project Engineer-Testing and Logging
L. J. Scopel	Project Geologist

Operations

G. C. Welch	Engineer
H. H. Sells	Engineer
F. J. Kirchman	Engineer
J. C. Bosio	Engineer
H. B. Shirley	Geologist

Advisory

G. R. Downs	Geology
M. S. Legge	Drilling Analysis
C. E. Haskett	Design Engineer
E. O. Gregory	Design Engineer

Loffland Brothers Company

The drilling operations staff of Loffland Brothers Company was available for consultation throughout the drilling of the well. Mr. W. C. Walker, the division manager in Casper, Wyoming, was in daily contact with the drilling operation through his superintendent, Mr. K. W. Conner and the location drilling foreman (toolpusher) Mr. Louis Brown. Mr. Brown was in close 24-hour contact with the well. This team of drilling experts was supported by the Loffland drilling engineering staff in Casper, Wyoming, and in Tulsa, Oklahoma.

Service and Equipment Companies

Contract DA-6033 included provisions that required E. A. Polumbus, Jr., and Associates, Inc., to procure specialized services and/or equipment as needed during the drilling and completion of the well. Following is a list of companies that provided such services and/or equipment.

Acme Tool Transportation, Inc.	A. J. & J. Welding Service
Armco National Supply Division Armco Steel Corporation	Associated Oil Field Rentals Division of Homco
Aurora Sand & Gravel Co.	Aurora Welding & Repair Service
Baash-Ross Division of Joy Manufacturing Co.	Baker Oil Tools, Inc.
Bethlehem Steel Company	Baroid Division National Lead Company
Bromley and Siebert Excavating, Inc.	Cable Drilling, Temperature and Well Servicing Co.
Continental-Emsco Company	Core Laboratories, Inc.
Cox Welding Service	Dalgarno Transportation, Inc.
The Denver and Rio Grande Western Railroad Co.	Dowell Division of the Dow Chemical Co.
Drilco Oil Tools, Inc.	Drilling & Service, Inc.
Duke's Truct & Auto Repair	The Farley Machine Works Co.
Frohlick Crane Service	Grant Oil Tool Company
G. & L. Tractor Service, Inc.	Hagan Chemicals & Controls, Inc.
Halliburton Company	Houston Oil Field Material Company, Inc.
John Bunning Transfer Co., Inc.	Lane-Wells Company
Maddox Oil Company	Mid-Continent Supply Co., Inc.
Miers Well Service, Inc.	Mine & Smelter Supply Co.
Miner Machine Company	Oil Well Perforators, Inc.
O'Quinn & Murray, Inc.	Power Rental Equipjent, Inc.
Prestons Welding Service	Schlumberger Well Surveying Corporation

Tombin Transportation Company

Well Completions Incorporated

Wright Petroleum Laboratories

Treasurer of the United States
Headquarters, Rocky Mountain Arsenal

Winslow Crane Service

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PROSPECTIVE INJECTION RESERVOIRS (VIII)

PROSPECTIVE INJECTION RESERVOIRS

SELECTION PARAMETERS

In the Final Design Analysis for the Rocky Mountain Arsenal Pressure Injection Disposal well eight of the geologic formations or units to be penetrated were considered as objective horizons in the search for an injection reservoir. The well was completed with the lowermost 70 feet of the well bore, in fractured pre-Cambrian rock, being tested as the initial injection reservoir. This section had not been predicted as a prospective injection reservoir.

The stratigraphic section and the mechanical aspects of the well are summarized in the frontispiece. Table 1 also shows the details of the stratigraphic section.

The interval under test is exposed in the open hole below the 5 1/2-inch liner. Regardless of the results of the initial fluid injection it is to be expected that at some time in the future this disposal reservoir will have accepted its capacity of waste fluids at designed injection pressures and a new injection reservoir will have to be sought in the cased portions of the hole. When or before this occurs the potential of the various strata in the well to serve as a waste disposal reservoir should be evaluated. Selection of the next reservoir to be tested will be based not only on the relative merits of the strata, but also on operational factors.

It is not within the scope of this report to present a detailed evaluation of the waste disposal reservoir potential of all of the strata of the well. However, a brief discussion of the necessary considerations for such an evaluation is presented and the observed physical characteristics of the various formations are summarized.

There are two basic considerations in estimating the potential of subsurface strata to serve as an injection reservoir, i.e., storage capacity of the rocks and accessibility to this storage. More commonly expressed, it is necessary to ascertain if there is porosity in the rock indicating the existence of storage space and if permeability is present to permit fluid to enter the pore space at desired rates and pressures. The quantitative inter-relationships of these factors and other considerations such as friction and volume are complex, but the basic requirement is permeability and porosity.

Most rocks exhibit some degree of natural permeability and porosity. The natural permeability and porosity of unsealed indigenous fractures in the rocks are also important considerations in that they provide large areal access to the pore space in the matrix rock. Furthermore, fractures can be induced or natural fractures can be enhanced by mechanical means. In calcareous materials acid treatment can increase permeability near the well bore and thus provide increased access to the matrix material.

An idealized injection reservoir would have an interval of highly porous and permeable rock. Open fractures, either natural or induced, would be present, if necessary, to provide rapid distribution of the fluid from the well bore and to give widely distributed contact of the fluid to the porous and permeable rock. Lacking these idealized conditions, compromises and adjustments have to be accepted.

In the case of the Arsenal well, it can be stated that in all cases the rocks penetrated in the various objective zones, exhibited low porosities and very low permeabilities. It is doubtful that sufficient matrix permeability and porosity exist to establish any one of the objective zones as a reservoir utilizing a practical thickness of this rock. However, numerous fractures were observed in cores, in portions of a large interval in the well, and additional fracturing is inferred and interpreted to exist from log data and lost circulation occurrences.

It is believed, therefore, that in selecting injection zones in the Arsenal well that determination of the more highly fractured zones will be a prime consideration. Secondarily, the matrix characteristics of the various fractured zones should be compared. These factors should then be considered and balanced against the operational factors before selecting a zone to be tested.

Since the Arsenal well is located a considerable distance from other wells penetrating the same sediments, and since it is so far removed from

the outcrop area, extrapolations are not possible. Thus, it is necessary to assume that the physical characteristics observed in the well bore will be continuous over the radius of influence of the well.

In the programming and the drilling of the Arsenal well, gathering of data was a prime consideration. Economics and operational considerations sometimes forced modifications of this program, but every effort was made to obtain the necessary data for evaluation of the injection reservoir potential of the strata penetrated.

Some of the more important tools and data to aid in this evaluation are listed below:

Cores

- Descriptions
- Analyses

Formation Logs

- Sample Descriptions
- Induction-Electric Logs
- Micrologs
- Sonic Logs
- Gamma Ray-Neutron Logs
- Mud Logs

Drill Stem Tests

Drilling Records

- Penetration Rate Changes
- Lost Circulation Zones

Cores

Cores are the most positive indication of subsurface conditions available. With them it is possible to examine an actual piece of the formation of significant size. The lithology and physical makeup can be seen, fractures can be observed and direct measurements of the physical characteristics of the rock can be made.

Among the most important core measurements available from the pressure injection well at the present time are the matrix permeabilities and porosities measured on the recovered cores. The descriptions of the frequency, size and nature of fractures are also very valuable.

The limitations of core data should be recognized. Cores only provide data over a limited interval. Extrapolations are made and continuity of character is frequently assumed, but the quality of such data is dependent on the percentage of total section cored and the manner of selection of the cored interval. For example, cores objectively taken at pre-determined intervals are statistically more representative of the characteristics of the total section than cores taken wherever some favorable formation characteristics were noted.

During the drilling of the Arsenal well, a total of 28 cores were attempted. These cores cut 639 feet of section from which 575 feet were recovered. This gives a recovery percentage of 90 percent. Table 7 lists the cored intervals and formations as well as the recoveries.

Formation Logs

Because of economic and operational limitations, evaluation tools such as cores and drill stem tests are only used in selected or limited portions of a hole. On the contrary the various formation logs normally provide data for the full section penetrated. Most types of logs, however, are records of measurements or observations of various physical properties of the strata. Most frequently these data are not directly applicable to reservoir problems and to be usable, interpretations and calculations based on theoretical or empirical relationships are required.

From the sample logs and the various electrical logs the lithology and thickness of the strata can be determined. The quality of data from a sample log is dependent on such factors as the nature of the rock, the drilling rate, and the nature of the drilling fluids. The primary application is the determination of lithology and only qualitative observations of reservoir parameters such as permeability and porosity are possible.

In addition to their application in the determination of lithology and thickness of strata, the various electrical logs can be utilized in calculating porosities. Especially where core data is available for checking and calibration, usable porosity data can be calculated from the logs.

At the present time there are no recommendable interpretative techniques to estimate formation permeability from the formation logs.

The Sonic log is the most useful tool in calculating porosity, and in addition it gives valuable indications regarding the possible location of fractures or fracture zones. Although these data are not completely definitive, the indications are sufficiently reliable to be used as supporting evidence. One shortcoming of the Sonic log in locating fractures is that it gives no indication of vertical fractures.

A summary of the various logs taken during the drilling and completion of the Arsenal well is shown in Table 24.

<u>Drill Stem Tests</u>

From successful drill stem tests, data can be obtained in regard to the fluid contained in the rock, the reservoir pressure, and the overall capacity of the tested interval to transmit fluid. Each of these is applicable in the evaluation of prospective injection reservoirs.

From the standpoint of contamination, it is not desirable to inject waste fluids into any strata considered to have a potential for producing oil or gas within the effective area of the injection reservoir. Although the various samples and logs give some indications of the fluid content of the formation rocks, a drill stem test is the most positive means of actually sampling the formation fluid during the drilling of a well.

Injection in a reservoir is accomplished by compressing the natural reservoir fluids which are assumed to occupy 100 percent of the pore space in the rock at the natural reservoir pressure. The space thus created is

then occupied by the waste or injected fluid. If the natural reservoir pressures are abnormally high, excessive injection pressures are required.

The pressure of a reservoir can be obtained from the pressures recorded during a drill stem test or from extrapolations made from these pressures.

Calculations from drill stem test pressures may show the overall capacity of the tested interval to transmit fluids. This is, of course, directly applicable to the evaluation of the initial injection capacity of the interval.

A total of 14 drill stem tests including one wireline test were attempted in the well. Of these, ten of the drill stem tests were mechanically successful. Due to the low permeabilities in the rocks tested, it would have required prohibitively long testing periods to have obtained optimum pressure data. Therefore, in many of the tests, it will not be possible to make reliable quantitative pressure interpretations.

The details of each test are shown in Tables 9 through 22. A summary of the tests and intervals is shown on page 53.

Drilling Records

One of the most valuable tools to assist in evaluating prospective injection horizons is the record contained in the drilling log of occurrences of lost circulation while drilling.

When lost circulation occurs, it means that in the strata being drilled or in some portion of the strata already drilled, the natural reservoir pressure has been exceeded by the hydrostatic pressure of the mud column to the extent that mud is being injected into that strata. In essence, by accident, the well becomes an injection well during the period of the mud loss.

The identification or location of the interval of lost circulation is not always possible. However, most frequently the lost circulation occurs in the zone being drilled. A careful analysis of penetration rates, mud characteristics, remedial procedures used and well performance after the resumption of drilling must be coupled with other analyses of cores and formation logs before an interpretation of the location of a lost circulation zone is made. Lost circulation occurrences are graphically portrayed in Figure 10.

PROSPECTIVE INJECTION RESERVOIRS (CON'T)

CHARACTERISTICS OF POTENTIAL INJECTION RESERVOIRS PENETRATED

In the Final Design Analysis, all of the anticipated objective injection reservoirs to be penetrated in the Arsenal well were considered and discussed. These included the Hygiene sandstone zone, the Codell sandstone, the "J" sandstone, the Dakota sandstone, the Lakota sandstone, the Morrison formation, the Lyons formation, and the Fountain formation. The fractured pre-Cambrian rock interval which is being initially tested was not originally predicted to be a possible injection reservoir.

In the following discussions frequent reference is made to specific data regarding the various strata. The following list shows where these various data are found in the report:

Stratigraphic section	Frontispiece and Table 1
Sample and core descriptions	Sample log - Vol. III
Core descriptions	Table 2
Core analyses	Logs - Vol. III, Table 23
Summary of cores	Table 7
Drill stem test summary	Page 53
Drill stem test results	Tables 9 to 22
Formation logs	Vol. III
Drilling records	Figure 10 and Vol. II

Hygiene Sandstone

The Hygiene sandstone zone in the Arsenal well is composed primarily of sandy shales. Since no sandstone development of significance was noted, this zone is regarded as having no potential as an injection reservoir.

Codell Sandstone

There was no recognizable development of the Codell sandstone in the Arsenal well.

"J" Sandstone

The 120-foot interval of "J" sandstone in the Arsenal well between 8,485 and 8,605 feet consists of a 45-foot section of quartzitic sandstone containing slight oil staining and some fracturing and 75 feet of intermixed, quartzitic sandstone and dark grey shales.

A total of 62 feet of "J" sandstone was cut in two cores in which the recovery was 100 percent.

From the sandstones recovered, a total of 38 core samples were analyzed. All permeabilities were less than one millidarcy. Porosities ranging from 11.2 percent to 2.1 percent were measured with the arithmetic average porosity being 5.7 percent.

Oil saturations were noted in the "J" sandstone core samples to a depth of 8,525 feet. Visual examination showed this to be spotty saturation.

A drill stem test was taken in the 8,482 to 8,556 foot interval which includes the better developed sandstones and more especially the interval which showed oil staining. The tool was open one hour and recovered only 200 feet of slightly gas-cut mud.

Qualitative analysis of the Sonic log shows some possible fracturing in the "J" sandstone interval. There were no mud losses in the section during the drilling and coring operations.

The quality of the "J" sandstone as evidenced by the core and log data and the poor recovery in the drill stem test eliminates the "J" sandstone as a potential injection reservoir in this well.

Dakota-Lakota Sandstones

The Dakota-Lakota sandstones are in the 153-foot interval between 8,633 and 8,786 feet in the Arsenal well. The upper sandstones (Dakota) are characterized as being of fine to medium grain size and hard to quartzitic. The Lakota sandstones are fine grained and quartzitic. Both contain some shaly sandstone and a 20-foot shale section separates the two units.

Three cores were taken in the Dakota sandstone. Of the total of 52 feet of section cut, 50 feet were recovered. This represents a recovery of 96 percent.

Thirty-one samples of sandstone from the cores were analyzed. With two exceptions the permeabilities were less than one millidarcy. One sample showed 1.4 md. and one sample, described as fractured, showed 3.5 millidarcies permeability. The porosities ranged from 8.5 percent to 1.7 percent with the arithmetic average being 4.6 percent.

One drill stem test was taken across the interval from 8,628 to 8,821 feet. This includes the Dakota and Lakota sandstones and an upper shaly portion of the Morrison formation. The tool was open one hour and only 400 feet of slightly gas-cut mud was recovered.

A qualitative interpretation of the Sonic log shows some possible fracturing, but this was not verified in the sections cored. There were no mud losses noted during the drilling and coring of the interval.

On the basis of the data obtained, the Dakota-Lakota sandstones are not considered to be potential injection reservoirs in this well.

Morrison Formation

During the drilling of the 186 foot interval of the Morrison formation penetrated between 8,786 and 8,972 feet none of the strata exhibited characteristics of sufficient quality to warrant coring or drill stem testing.

From a qualitative analysis of the well logs and other well data, none of the zones are indicated to have significant porosity or indications or permeability to be of interest. Thus, the Morrison formation is not believed to have any potential as an injection reservoir.

Lykins Formation

The Lykins formation is 610 feet thick and was encountered in the interval between 8,972 and 9,582 feet. The sediments are red, silty shales with the exception of 15 feet of fine grained quartzitic sandstone near the top of the formation and an 80 foot section of anhydrite and red shale near the base of the formation.

There were no cores or drill stem tests taken in this interval. Some possible fracturing in the 15 foot sandstone interval is indicated by the Sonic log. This sandstone is not considered to be of sufficient thickness

for it to be considered as a potential injection reservoir. The only possibility would be to combine this unit with other potential reservoirs.

Lyons Formation

The Lyons formation was encountered in the 190-foot interval between 9,582 and 9,772 feet in the Arsenal well. It consists of fine-grained orange quartzitic sandstone with thin red to maroon shales.

A total of 95 feet of section was cut in 8 cores taken in the Lyons formation. From this interval 84 feet were recovered which represents an 88 percent recovery.

One hundred thirty-two samples of sandstones from the cores were analyzed. With one exception the permeabilities were less than one millidarcy. The observed porosities ranged from 7.1 to 1.0 percent with the arithmetic average porosity being 3.1 percent.

Extensive fracturing was observed throughout the cores recovered in the Lyons formation. Some of the fractures are closed and others are described as hairline fractures of several inches to open fractures one to two feet in length.

Due to the anticipated mechanical difficulties associated with the presence of fractures and the occurrences of lost circulation and the possibility of loose sand being produced during testing, no attempts were made to test the Lyons formation with conventional drill stem test tools. As an alternative means, one formation test was attempted utilizing the Schlumberger Formation Interval Tester. This test was unsuccessful due to plugging of the tool with lost circulation material in the drilling mud.

Indications of fracturing in some of the drilled intervals in the formation are noted on the Sonic log. These indications are found principally in the top 130 feet of the formation.

The first lost circulation in the well occurred shortly after drilling into the Lyons formation. A total of eight instances of mud losses were noted in drilling this formation. These ranged in severity from a 10-barrel loss to a 320-barrel loss per occasion.

In the Lyons formation there is a higher density of favorable indications of the zone having the qualifications necessary for a disposal reservoir than in any other interval penetrated. However, it should be mentioned that there is a heavy concentration of core data in the upper 140 feet of the formation. In some of the subsequent drilling, coring was not undertaken due to mechanical and economic considerations. Furthermore, the occurrences of lost circulation may have decreased in subsequent drilling as a result of experience gained while drilling in the Lyons formation.

On the basis of the various characteristics observed it can be stated that the Lyons formation contains prospective injection reservoirs and future testing of this interval is definitely warranted.

Fountain Formation

A total interval of 2, 108 feet of Fountain formation was penetrated between 9, 772 and 11, 880 feet in the Arsenal well. The upper 110 feet of the formation consists of fine grained feldspathic sandstones, siltstones,

and maroon shales. Below this interval the sediments are primarily arkosic sandstones and conglomerates and red and green shales. The cement for the clastics may be calcareous materials or a combination of calcareous and clay materials.

A total of 408 feet of section was cut in 13 cores taken in the Fountain Formation. The recovery of 359.5 feet represents 88 percent.

The 220 samples analyzed contained 37 samples which showed permeabilities of one millidarcy or greater. The majority of these higher permeabilities are found in the interval between 11,265 and 11,300 feet.

The porosities measured in the formation ranged from 7.8 to 0.8 percent with the arithmetic average being 3.2 percent. Of interest is the fact that the average porosity associated with the 37 samples showing permeabilities of one millidarcy or greater is 4.8 percent.

The cores showed a high degree of fracturing to a depth of 10,400 feet. Below this depth only scattered fracturing was observed in the cores; however, a preliminary interpretation of the Sonic log shows possibilities of scattered fracturing in intervals throughout the formation.

Eleven attempts were made to drill stem test portions of the Fountain formation. Three tests were unsuccessful, but some of the remaining tests yielded usable pressure data. Fluid recoveries were drilling mud or mud contaminated formation water in all but one instance. In test No. 14 which covered the lower portion of the Fountain formation into the pre-Cambrian rocks, 5,400 feet of salt water was recovered.

Numerous occurrences of lost circulation were experienced while drilling and coring in the Fountain formation. The greater number of these mud losses occurred in the interval between 9,960 and 10,250 feet. The lowermost mud loss took place at 11,080 and was the most serious in the well with some 1,350 barrels being lost.

As might be expected, the zone where mud loss frequencies were high and the zones where fractures were observed coincide in part. This general interval from the top of the Fountain at 9,772 to a depth of 10,400 feet is thus considered to warrant consideration as a prospective injection reservoir.

The zone of higher permeability noted in the core analyses from 11,265 to 11,300 should be carefully analyzed and any other zones showing similar log characteristics should be carefully investigated. Though the average permeability is only 1.7 millidarcies, the nature of this material can be prospective of an injection reservoir if sufficient thickness exists.

Due to the widespread indications of possible fracturing, the entire Fountain formation warrants analysis for injection reservoir prospects, but these two zones specifically mentioned should be given special attention.

Pre-Fountain Regolith

The pre-Fountain Regolith encountered between 11,800 feet and 11,985 feet in the Arsenal well is not believed to have prospects as an injection reservoir due to the predominantly shaly nature of the sediments.

Ordovician? Cambrian?

In the 55 foot interval of Ordovician? Cambrian? sediments encountered between 11,895 to 11,950 feet there is one 15-foot section of conglomerate and one 10-foot section of dolomite.

Aside from the logs there are no other interpretative data for this interval. A qualitative interpretation of the logs shows sufficient favorable indications to warrant a detailed analysis of these two units.

Pre-Cambrian

The pre-Cambrian rocks were drilled from 11,950 feet to the total depth of the hole at 12,045 feet. The upper 20 feet are a weathered schist and the remainder of the hole drilled in a fractured granite hornblende gneiss containing pegmatite intrusions.

One core in the pre-Cambrian rocks recovered seven feet of the 9 feet cut. No permeability and porosity determinations were made from this core. After cutting this core, lost circulation was experienced.

The final liner was set to 11,975 feet leaving the pre-Cambrian interval from 11,975 to 12,045 feet open. Preliminary injection testing showed the zone to be capable of initially accepting desired volumes of fluid within the pressure limitations imposed.

INDEX
CURSORY CONSIDERATIONS FOR INJECTION WELL OPERATIONS (IX)

CURSORY CONSIDERATIONS FOR INJECTION WELL OPERATIONS

The final phase of the construction of the disposal well was the physical completion and preliminary injection testing. Indications were that the open-hole interval was capable of accepting 400 to 800 gallons of water per minute with a corresponding surface pressure less than 2,000 psig. The duration of this capability has not yet been established.

STIMULATION

In the event that the disposal reservoir currently exposed to the wellbore stops accepting commercial quantities of waste water within the stipulated pressure limitations, two possibilities are present. First, if the storage capacity of this reservoir has been reached, another reservoir must be exposed by recompletion. Second, if the reservoir has not reached its storage capacity but has a flow impediment in the vicinity of the wellbore, remedial permeability repairs may be warranted. Among the possible repair methods are:

1. Acidizing - This approach could remove the impediment if the material causing the restriction is acid soluble.

2. Hydraulic Fracturing - This solution would create new channels of permeability and prop them open with suitable propping agents introduced in the fracture creating fluid.

3. Surfactant Treatments - This mechanism is to reduce surface tension values and thereby change wetting characteristics. Relative permeability or the ability to flow through a porous media is affected by the preferential wetting characteristics of the material.

4. Backwashing - This system induces the well to flow by release of surface back pressure. If the reservoir pressure is insufficient to cause flow to the surface, the well may have to be swabbed or pumped to clean the sand face.

5. Additional methods are available for stimulation treatments but are considerably more specialized in their applications.

An investigation of such items as pressure behavior, fluid composition, matrix rock characteristics, nature of the impediment, etc., is required to recommend the type and method of stimulation for the individual zone or zones to be treated.

FLUID COMPATIBILITIES

The large volume of fluid to be disposed of at the Rocky Mountain Arsenal prohibits complete chemical treatment due to economic considerations. The displacement of any undesirable fluid or matrix reaction precipitates from the immediate vicinity of the wellbore minimizes derogatory effects. For this reason a "buffer" water spearhead is injected to keep separated the natural formation connate waters and the injected waste fluids. This separation is effected until the connate waters have been displaced some 100 feet from the wellbore.

RESERVOIR EQUILIBRIUM

In addition to compatibility considerations, the injected water should have innate stability at reservoir conditions of temperature and pressure. In addition, the water must be relatively innert to the reservoir matrix rock.

CORROSION

Two corrosion possibilities exist with injection or producing wells. First there is the possibility of external attack and second the possibility of internal attack.

External

The action of ground waters and other sources of possible external corrosion should be minimized at the disposal well because of the complete isolation of the casing from the borehole by the cement sheath. Because of the cost involved in the disposal well, reliance on this sheath alone would not be good operating procedure. Periodic potentiometer surveys and possibly cathodic protection would be warranted. An evaluation of the severity of the problem should be made prior to the initiation of remedial steps.

Internal

The problem of internal corrosion should also be checked for severity prior to the initiation of extensive remedial steps. As a general point of interest, it is not recommended that the tubing be plastic coated, mainly because removal of the plastic coating by decomposition, erosion, abrasion from wireline tools, etc., could result in the deposition of plastic particles on the rock face. In addition, if a complete surface covering of plastic is not affected, there will be points of corrosive concentration which may lead to tubing failure.

There should be no difficulty in inhibiting attack, if it should occur, by the use of appropriate chemical inhibitors. An inhibitor should be selected which will not decompose into a viscous material that could plug the rock face.

The recommendations regarding corrosion are summarized as follows:

1. The injection string should not be plastic coated.

2. Surface equipment should be inspected at regular intervals to determine if internal attack is occurring. Consideration should be given to a test length of pipe especially installed for internal corrosion inspection purposes.

3. A caliper survey should be run in the injection tubing so that the extent of damage may be determined. Results of this survey will indicate if inhibitor injection should be commenced.

4. The possible use of coupons should be investigated. These are small pieces of metal placed in the flow stream which may be removed periodically to examine the extent of corrosion.

MIGRATION OF INJECTED FLUIDS

After a fluid has been discharged from a wellbore, two possibilities exist for its vertical migration:

1. Around the mechanical installation, and

2. Within the reservoirs themselves.

Indications from the cementation operations and from the subsequent testing are that the mechanical installation at the Rocky Mountain

Arsenal is sound. Vertical communication, therefore, if it were present, would probably be within the reservoirs. This possibility is minimized because of the massive shale bodies overlying the injection horizons thus providing natural segregation.

PLANT OPERATION

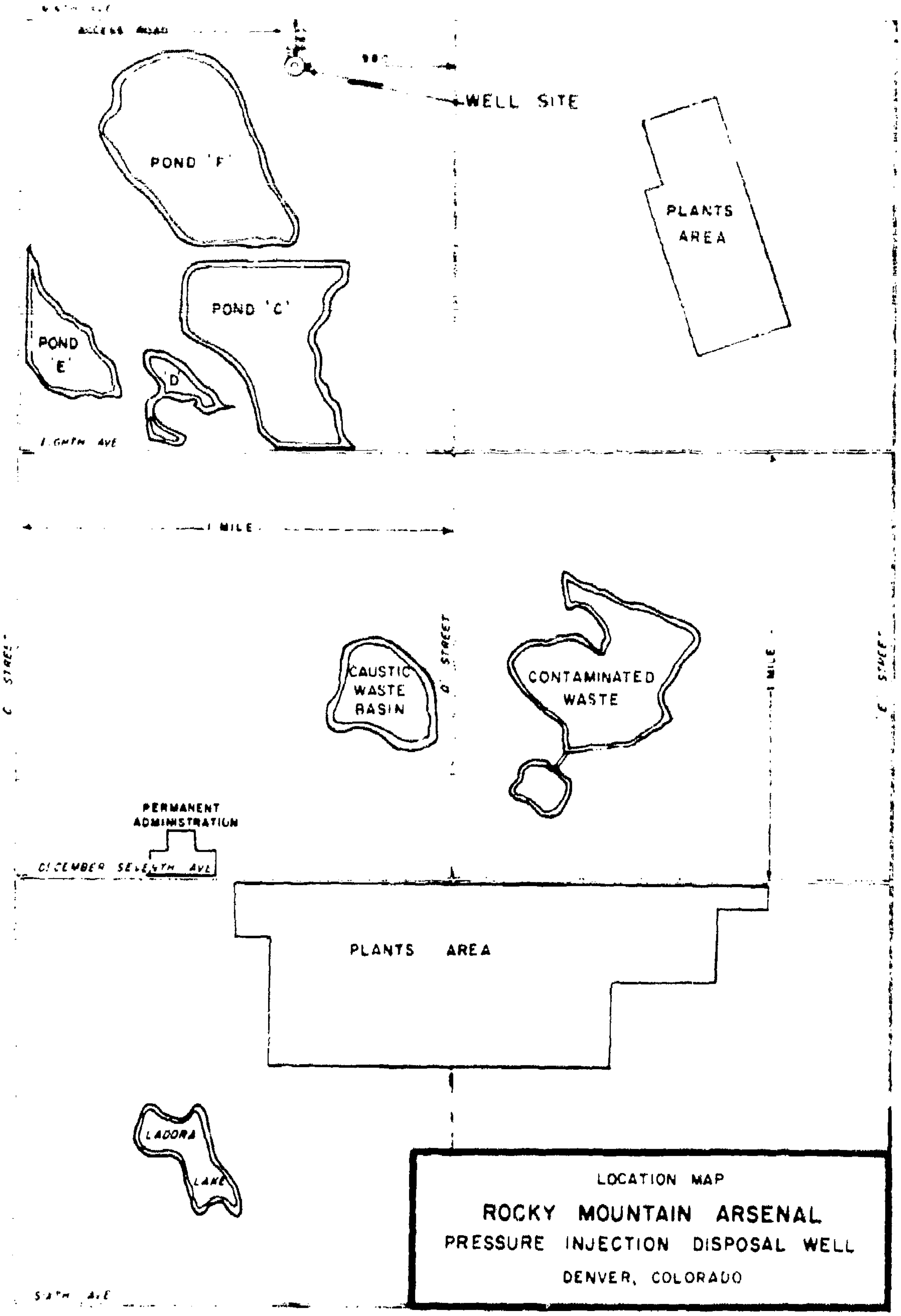
The existing surface facilities will be employed in the reservoir evaluation injection tests. The present installation has four triplex pumps capable of delivering 400 gallons per minute at 2,000 pounds surface pressure. Combinations of these pumps will provide variable rates and consequently, variable pressures conducive to reservoir evaluation techniques.

In subsequent operation of the disposal well plant, three parameters are of extreme importance from a reservoir analysis standpoint. They are time, volume, and pressure.

Volume recordings will give directly the accumulative capacity of the reservoir. The time notation will permit a volume per unit time, thus the rate of injection. The rate-pressure relationship is the criteria for reservoir behavior prognostication.

A careful day-to-day record of surface pressures, rates of injection, cumulative volumes injected and other pertinent observations by the field personnel would provide a firm basis for reservoir performance evaluation, possible stimulation requirements and analytical operating efficiencies.

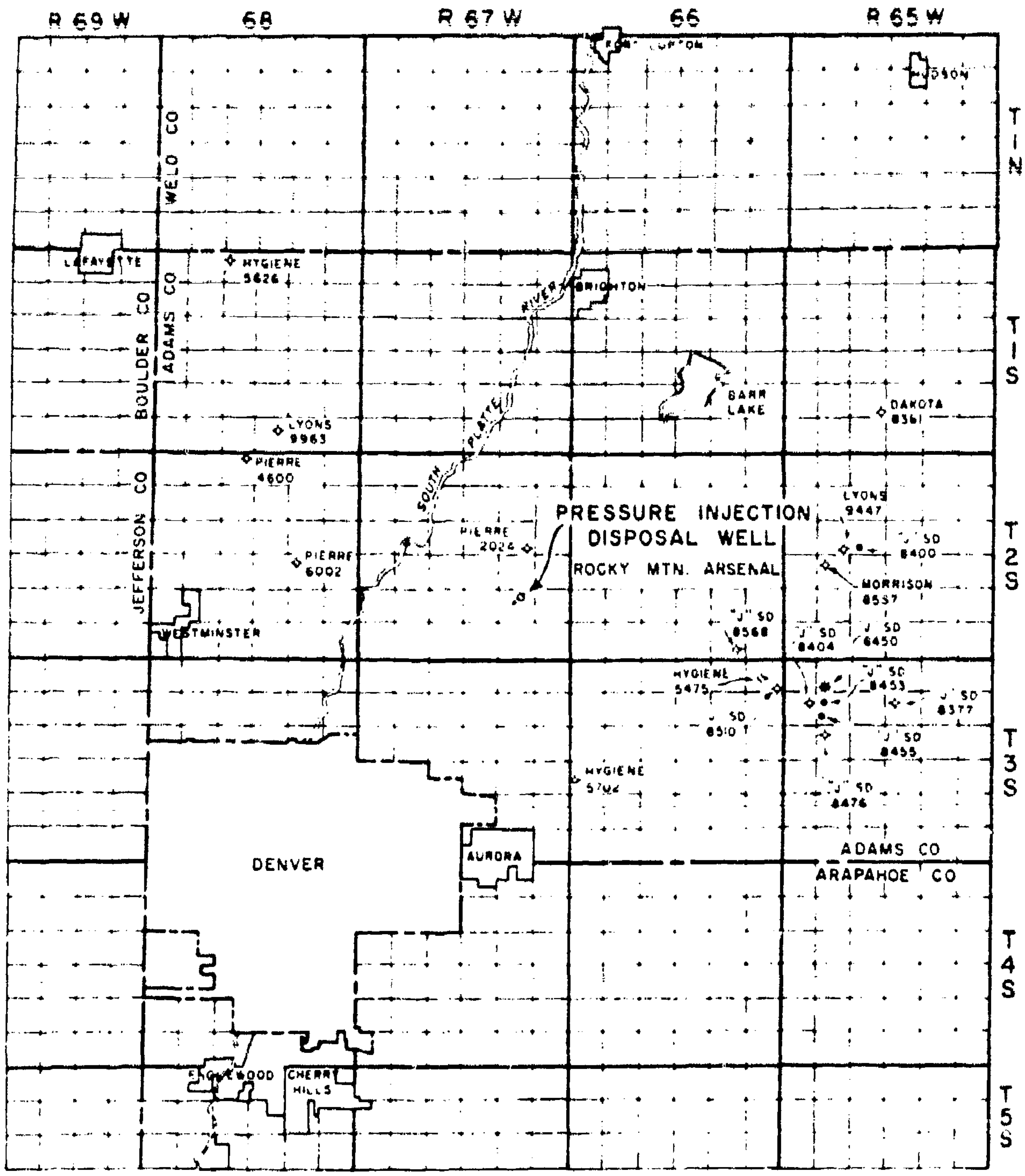
FIGURE



LOCATION MAP
ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
DENVER, COLORADO

C. A. POLUMBUS, JR. AND ASSOCIATES, INC.

Figure 2

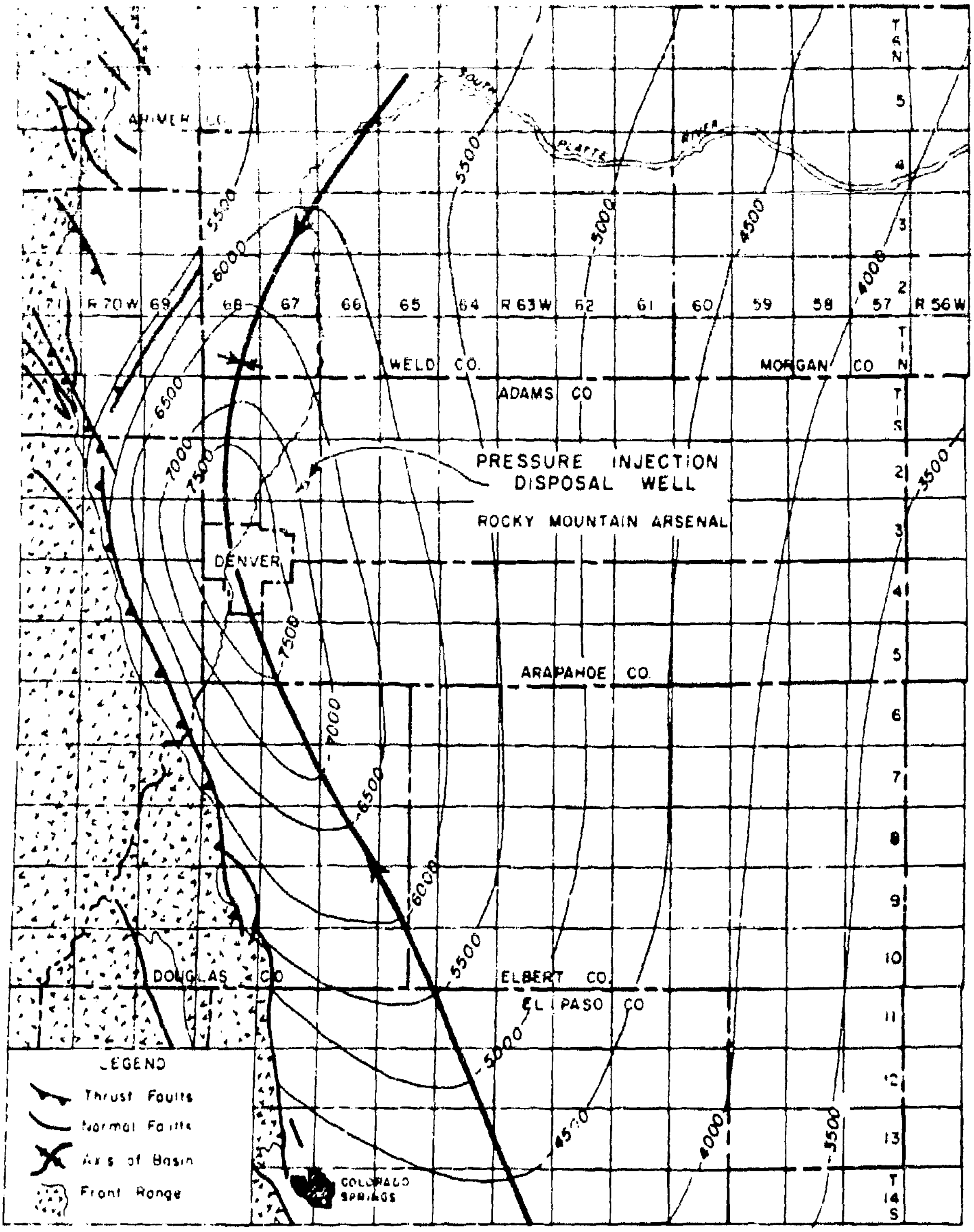


LEGEND

◊ "J" SD — Deepest Formation Penetrated
8450' — Total Depth

DEVELOPMENT MAP

FIGURE 3



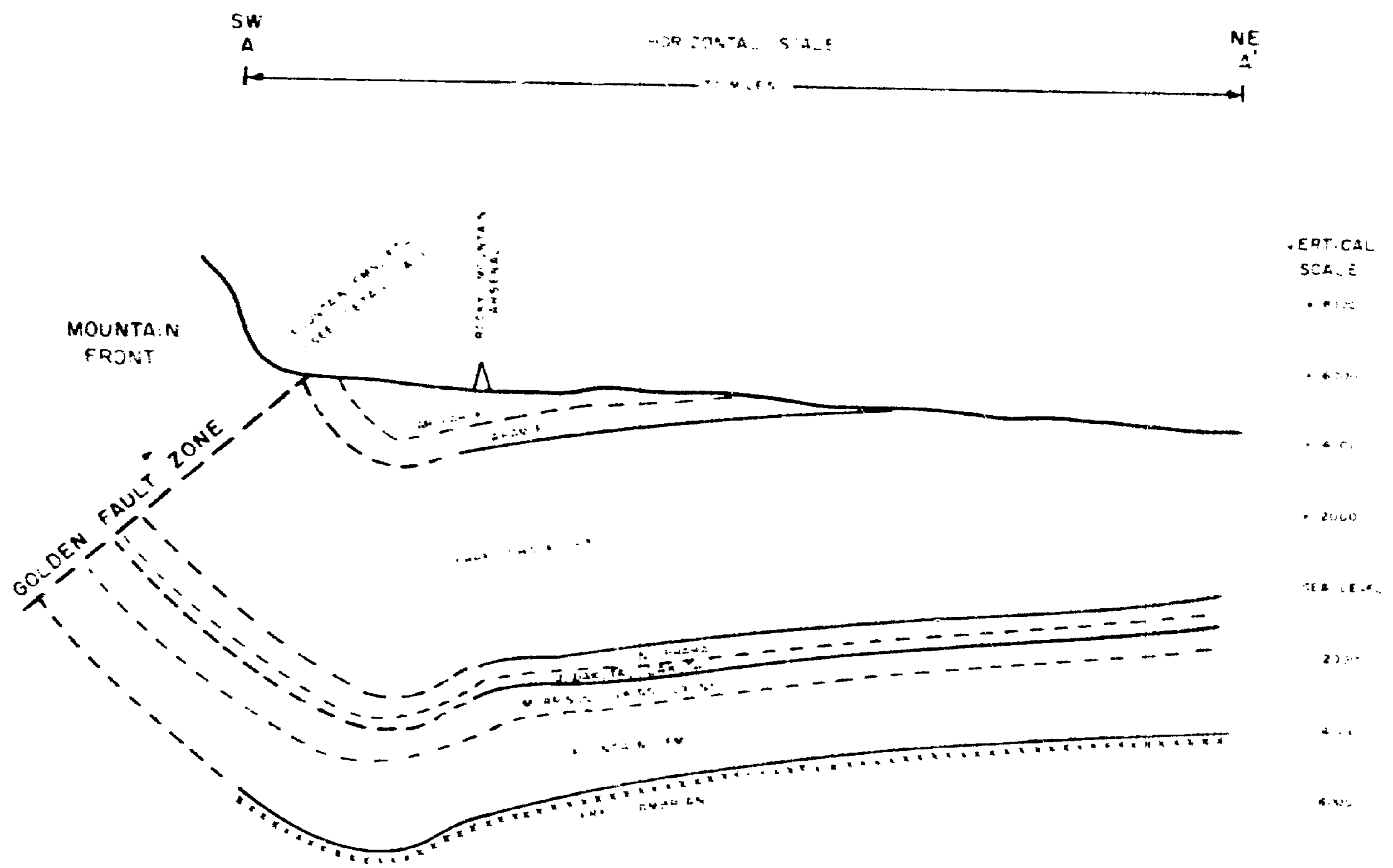
STRUCTURE MAP OF

SOUTHERN PORTION OF DENVER BASIN

CONTOURED ON PRE-CAMBRIAN SURFACE

CONTOUR INTERVAL = 500 FEET

E. A. POLUMBUS, JR. & ASSOCIATES, INC.



DIAGRAMMATIC CROSS SECTION

SOUTHWEST - NORTHWEST

FROM MOUNTAIN FRONT THROUGH ARSENAL WELL

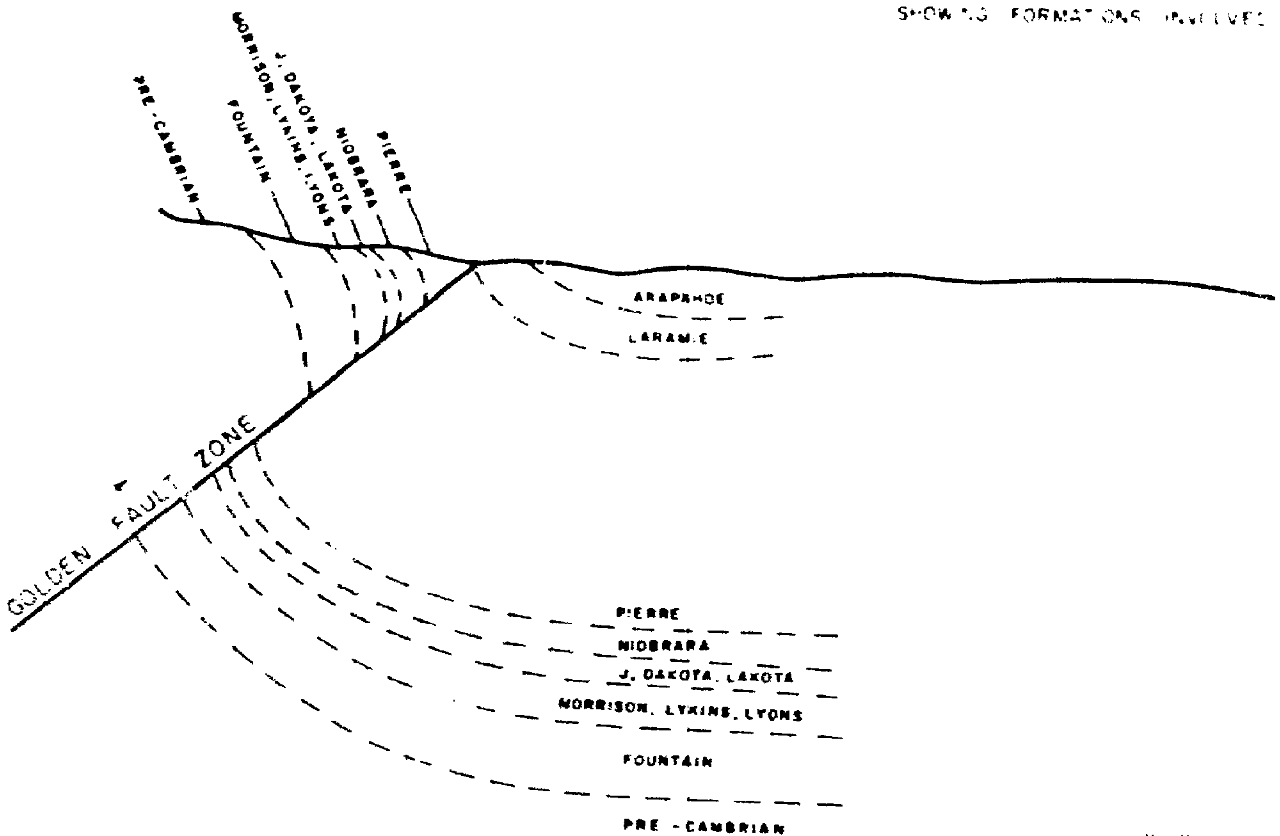
E. A. POLUMBUS, JR. AND ASSOCIATES, INC.

FIGURE 4

DIAGRAMMATIC CROSS SECTION

MOUNTAIN FRONT SOUTHWEST OF ARSENAL WELL

SHOWING FORMATIONS INVOLVED IN THRUST FAULT ZONE



Detail "A" From Cross Section

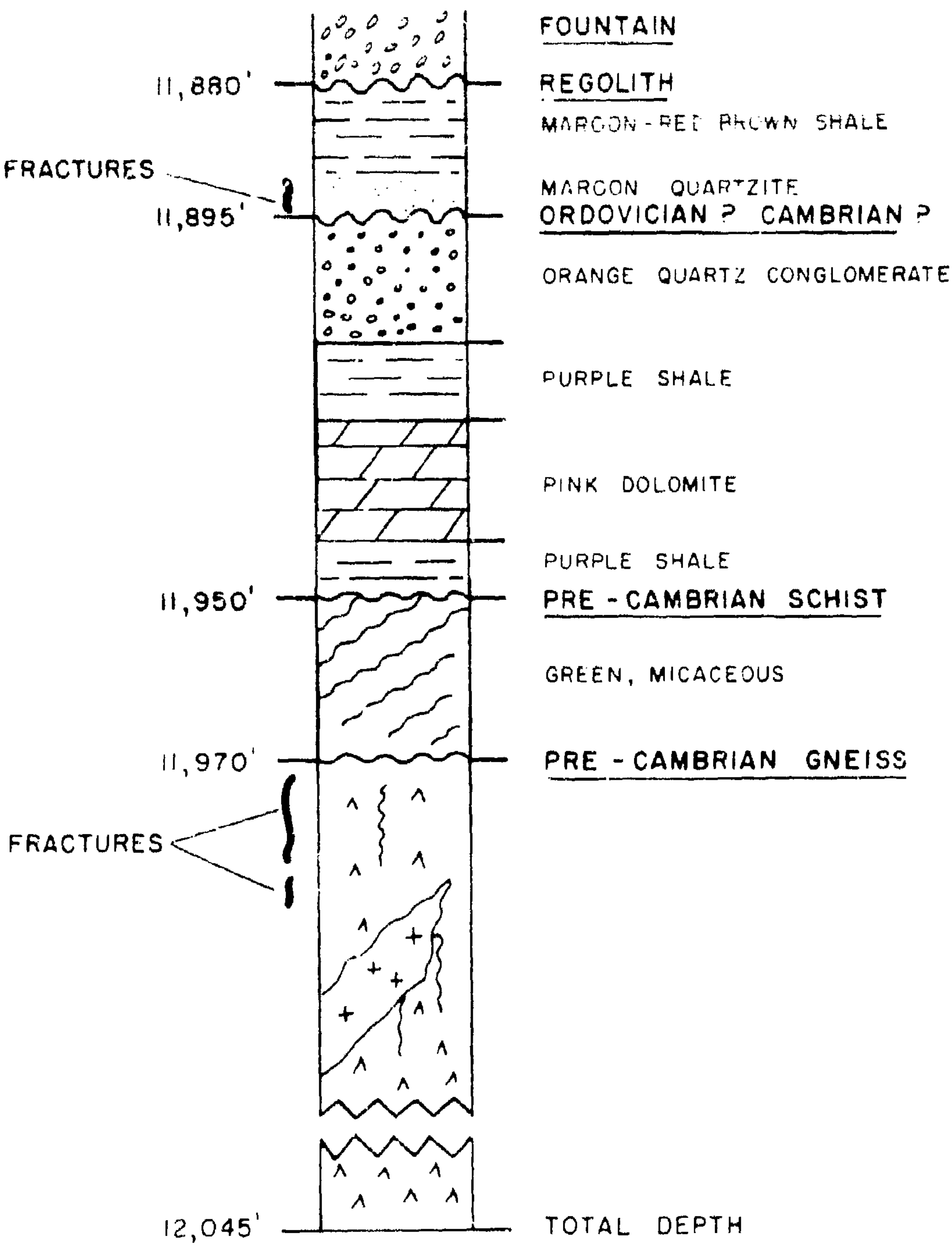
E. A. POLUMBUS, JR. AND ASSOCIATES, INC.

FIGURE 4A

FIGURE 5

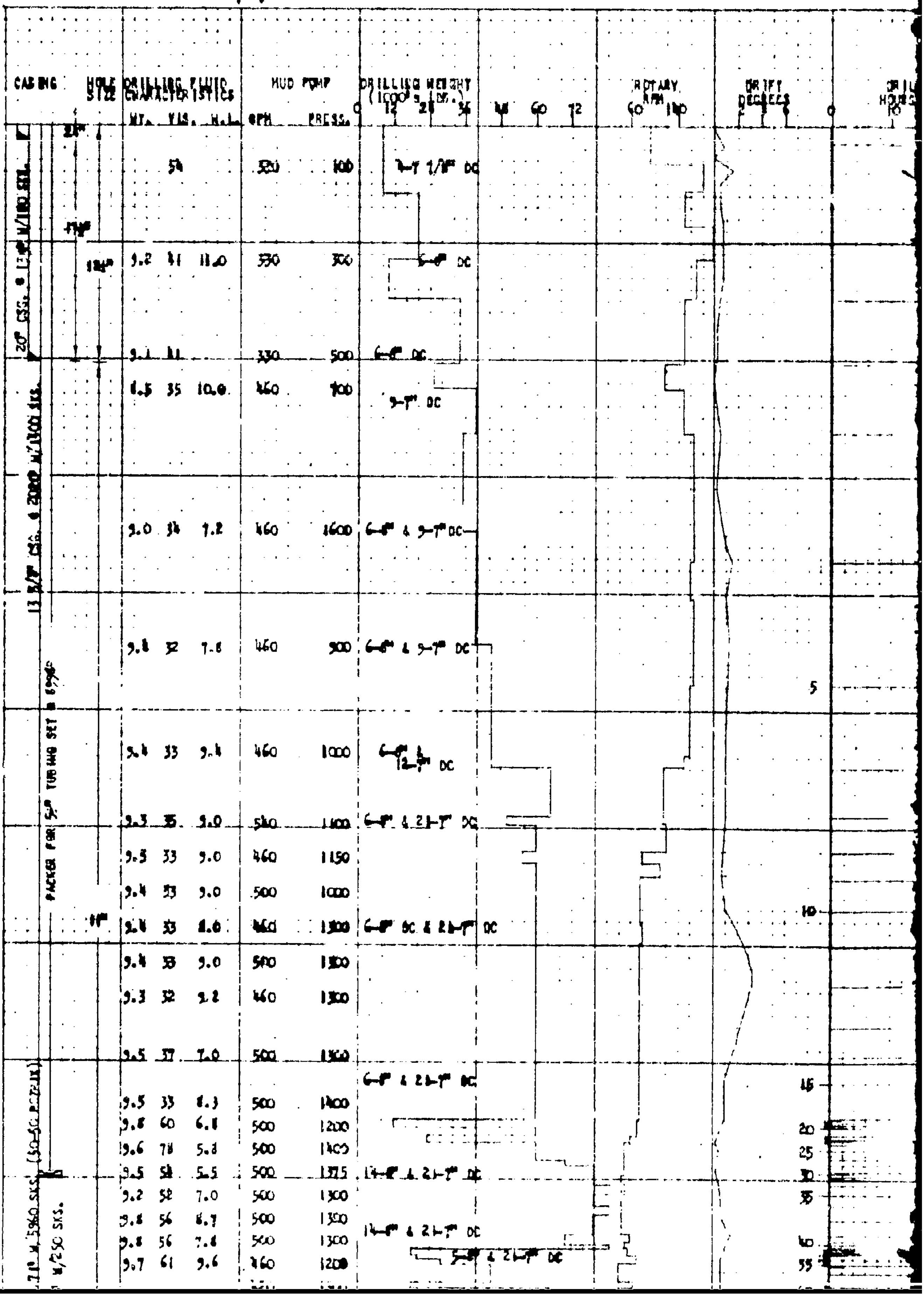
ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL

PRE - FOUNTAIN GEOLOGIC COLUMN



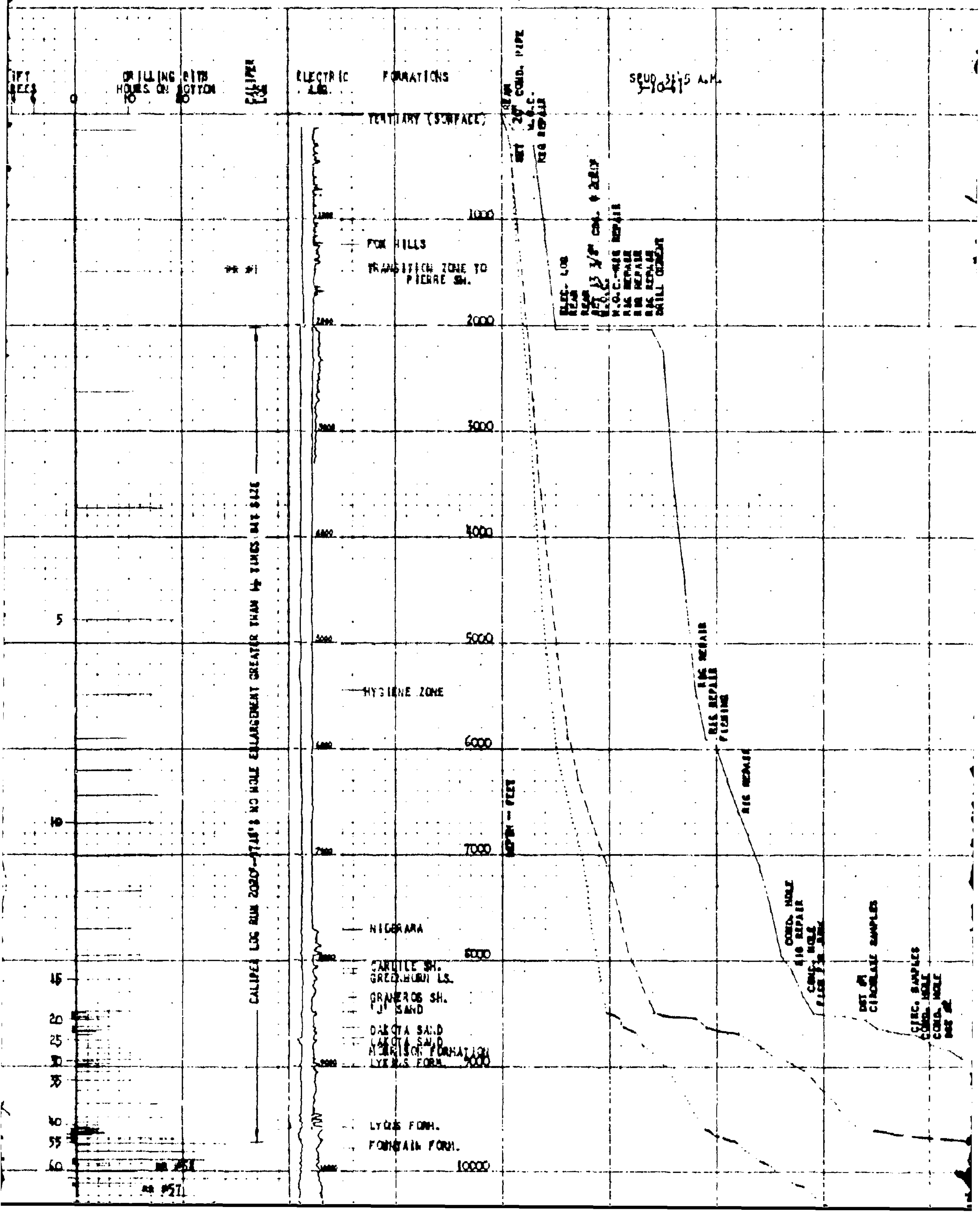
E. A. POLUMBUS JR. AND ASSOCIATES INC

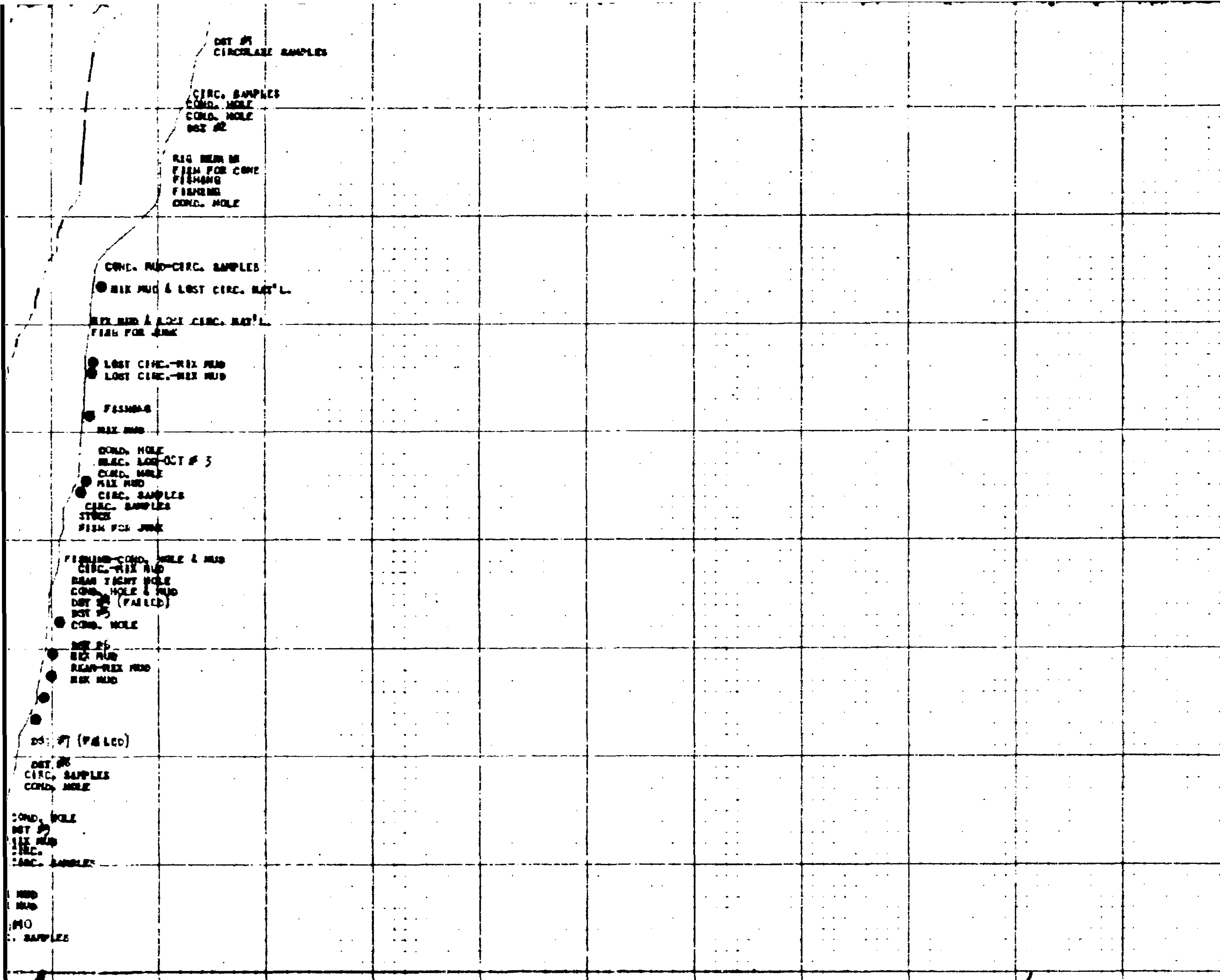
A



CASING
HOLE SIZE
DRILLING FLUID CHARACTERISTICS
WT. VIS. W.L.
MUD PUMP
GPM PRESS.
DRILLING WEIGHT (1000's LBS.)
0 12 24 36 48 60 72
ROTARY RPM
60 120
DRIFT DEGREES
DRILLING HOURS
20" CSG. @ 1300' W/1100 SKS.
13 3/8" CSG. @ 2000' W/1800 SKS.
PACKER FOR 5" TUBING SET @ 6900'
7" @ W/5960 SKS. (50-50 POZ-MIX)
W/250 SKS.
26"
17 1/2"
12 1/4"
8 1/2"
54 520 100 7-7 1/2" DC
9.2 41 11.0 330 300 5-8" DC
9.1 41 330 500 6-8" DC
8.5 35 10.0 460 900 9-7" DC
9.0 34 7.2 460 1600 6-8" & 9-7" DC
9.4 32 7.8 460 900 6-8" & 9-7" DC
9.4 33 9.4 460 1000 6-8" & 12-7" DC
9.3 35 9.0 540 1400 6-8" & 21-7" DC
9.5 33 9.0 460 1150
9.4 33 9.0 500 1000
9.4 33 8.6 460 1300 6-8" DC & 21-7" DC
9.4 33 9.0 500 1300
9.3 32 9.2 460 1300
9.5 37 7.0 500 1300
6-8" & 21-7" DC
9.5 33 8.3 500 1400
9.8 60 6.8 500 1200
9.6 78 5.8 500 1400
9.5 58 5.5 500 1375 14-8" & 21-7" DC
9.2 52 7.0 500 1300
9.8 56 6.7 500 1300
9.8 56 7.8 500 1300 14-8" & 21-7" DC
9.7 61 9.6 460 1200 5-8" & 21-7" DC
5
10
15
20
25
30
35
40
55

B


DRILLING BITS
HOURS ON BOTTOM
CALIPER
ELECTRIC LOG
FORMATIONS
SPUD 3:15 A.M.
TERTIARY (SURFACE)
FOX HILLS
TRANSITION ZONE TO PIERRE SH.
HYGIENE ZONE
NIOBRARA
CARLILE SH.
GREENHORN LS.
GRANEROS SH.
"J" SAND
DAKOTA SAND
LAKOTA SAND
MORRISON FORMATION
LYKINS FORM.
LYONS FORM.
FOUNTAIN FORM.
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
DEPTH - FEET
CALIPER LOG RUN 2020-9715' NO HOLE ENLARGEMENT GREATER THAN 4 TIMES BIT SIZE
SET 20" COND. PIPE
W.O.C.
RIG REPAIR
ELEC. LOG
RIG REPAIR
RIG REPAIR
FISHING
RIG REPAIR
CORE HOLE
RIG REPAIR
CIRCULATE SAMPLES
CIRC. SAMPLES
COND. HOLE
5
10
15
20
25
30
35
40
55
60



DST #1
CIRCULATE SAMPLES
CIRC. SAMPLES
COND. HOLE
COND. HOLE
DST #2
RIG REPAIR
FISH FOR CONE
FISHING
FISHING
COND. HOLE
COND. MUD-CIRC. SAMPLES
MIX MUD & LOST CIRC. MAT'L.
MIX MUD & LOST CIRC. MAT'L.
FISH FOR JUNK
LOST CIRC.-MIX MUD
LOST CIRC.-MIX MUD
FISHING
MIX MUD
COND. HOLE
ELEC. LOG-DST # 3
COND. HOLE
MIX MUD
CIRC. SAMPLES
CIRC. SAMPLES
STUCK
FISH FOR JUNK
FISHING-COND. HOLE & MUD
CIRC.-MIX MUD
REAM TIGHT HOLE
COND. HOLE & MUD
DST (FAILED)
DST #5
COND. HOLE
DST #6
MIX MUD
REAM-MIX MUD
MIX MUD
DST #7 (FAILED)
DST #8
CIRC. SAMPLES
COND. HOLE
COND. HOLE
DST #9
MIX MUD
CIRC.
CIRC. SAMPLES
SAMPLES

C

D

DRILLING BITS			DRILLING BITS		
BIT No.	TYPE	JET SIZE	BIT No.	TYPE	JET SIZE
52	2C		1	3CDT	
53	W7R		2	YT3	
54	W7R		3	OSC3J	1/2"
55	W7R		4	OSC3J	7/16"
56	W7R		5	DT	
57	ROBJ	1/2"	6	OSC3	
		7/8"	7	DT	
58	ROB2J	1/2"	8	OSC3	
		7/8"	9	YT1A	
59	W7R		10	OSC3	
60	44+J	1/2"	11	OSC3	
		7/8"	12	OSC3	
61	W7R		13	OSC3	
62	W7R		14	OSC3	
63	W7R		15	YT3	
64	W7R		16	DT20	
65	W7R		17	K2P	
66	W7R		18	W7R	
67	RG2BJ	7/8"	19	W7R	
68	RG2BJ	7/8"	20	W7R	
69	RG2BJ	7/8"	21	OWSV	
70	RG2BJ	7/8"	22	W7R	
71	W7R		23	W7R	
72	W7		24	W7R	
73	W7R		25	T2	
74	W7		26	W7R	
75	W7R		27	W7	
76	W7R		28	YM	
77	W7R		29	C2	
78	W7R		30	OWC	
79	W7		31	W7R	
80	OWC		32	W7R	
81	W7R		33	W7R	
82	W7R		34	OWC	
83	OWC		35	C2	
84	W7R		36	OSC1G	
85	W7R		37	OSC1G	
86	W7R		38	OSC1G	
87	W7R		39	YTL	
88	W7RJ	3/8"	40	OWS	
89	W7R		41	T2	
90	W7J	3/8"	42	W7R	
91	W7R		43	W7R	
92	W7R		44	2C	
93	W7RJ	3/8"	45	W7R	
94	W7R		46	W7R	
95	W7RJ	3/8"	47	W7R	
96	RG-1J	3/8"	48	W7R	
97	RG-1J	3/8"	49	W7R	
98	RG-1J	3/8"	50	W7R	
			51	W7R	

Note: 9-11" bits to condition hole, drill on junk, ream bridges and drilling cement.
1-6 3/4" bit used to drill junk.

CONTRACTOR LOFFLAND BROTHERS C

RIG DESCRIPTION

Drawworks Ideco FB 1050 Mast L. C.
Drill Engines 3 - Caterpillar D-397 DA
Continuous HP Rating 450Each Spe
Mud Pump Engine DCP Compound
Continuous HP Rating - at -
Mud Pumps (1) Emsco D-700 (7 1/2"
(2) Emsco D-500 (7 1/2"
(3)
Drill Pipe 4 1/2" 16.60# Tool Joint
Drill Collars 9-8" x 3" I.D. & 25-7"
Kelly 4 1/4" Sq. x 40' Standpipe
Swivel National R3-2 3/4"I.D Hose 3"

WATER SOURCE:

BIT SUMMARY

Size	No. Bits	Footage	No Hours	Feet/ Hour
			DRILLING	
12 1/4"	3	2030	46.2	43.9
11"	62.2	8711	710.6	12.2
6 3/4"	14.5	665	139.5	4.8
			REAMING	
24"	1	138	4.0	34.5
17 1/4"	2	1892	34.2	55.6
11"	17.8	520	138.0	3.8
6 3/4"	0.5	146	6.7	21.8
			DIAMOND	CORING
8 7/8"	3	191	100.5	1.9
8 9/16"	1	18	9.5	1.9
7 13/16"	2	282	130.2	2.2
6 11/16"	3	142	51.2	2.8
Dia. Bowen Basket 6			-	-

LEGEND

DRILLING CURVES

——— Overall Drilling Progress Curve

- - - - Net Drilling Progress Curve: (Includes o mal trips, connections, drift surveys, r mixing, i. e. related to normal drilling p

. . . . . . Rotating Progress Curve

Coring

Diamond Drilling

Red Arrow: Highlights hazards

● Lost Circulation Occurence including m

◆ Spot Lost Circulation, Cement Plug

▼ Cleanout Difficulties–Trip In

▲ Tight Hole–Pulling Out

DRILLING BITS

RR–Rerun Bits

Rm–Reaming Bits for Core Hole

–Diamond Drilling

–Diamond Coring

E

CONTRACTOR LOFFLAND BROTHERS COMPANY

RIG DESCRIPTION Rig No. 7

Drawworks Ideco FH 1050 Mast L. C. Moore - 142'
Drill Engines 3 - Caterpillar D-397 Diesel
Continuous HP Rating 450Ea at Speed Operated
Mud Pump Engine Off Compound
Continuous HP Rating - at - RPM
Mud Pumps (1) Emsco D-700 (7 1/2" x 16")
(2) Emsco D-500 (7 1/2" x 16")
(3)
Drill Pipe 4 1/2" 16.60# Tool Joint X Hole
Drill Collars 9.8" x 3" I.D. & 25.7" x 2 3/4" I.D.
Kelly 4 1/4" Sq. x 40' Standpipe 4 1/2" x 55'
Swivel National R3-2 3/4" I.D Hose 3" x 55'
WATER SOURCE:

BIT SUMMARY

Size	No. Bits	Footage	No. Hours	Feet/ Hour	Feet/ Bit	Hrs. On Bot/Bit
			DRILLING			
12 1/4"	3	2030	46.2	43.9	677	15.4
11"	62.2	8711	710.6	12.2	140	11.4
6 3/4"	14.5	665	139.5	4.8	46	9.6
			REAMING			
24"	1	138	4.0	34.5	138	4.0
17 1/4"	2	1892	34.2	55.6	946	17.1
11"	17.8	520	138.0	3.8	29	7.7
6 3/4"	0.5	146	6.7	21.8	292	13.4
			DIAMOND	CORING		
8 7/8"	3	191	100.5	1.9	-	-
8 9/16"	1	18	9.5	1.9	-	-
7 13/16"	2	282	130.2	2.2	-	-
6 11/16"	3	142	51.2	2.8	-	-
Dia. Bowen Basket 6			-	-	-	-

LEGEND

DRILLING CURVES

Overall Drilling Progress Curve

Net Drilling Progress Curve: (Includes only time on bottom, normal trips, connections, drift surveys, rig service, normal mud mixing, i. e. related to normal drilling progress.)

Rotating Progress Curve

Coring

Diamond Drilling

Red Arrow: Highlights hazards

Lost Circulation Occurence Including mixing L. C. mud

Spot Lost Circulation, Cement Plug

Cleanout Difficulties–Trip In

Tight Hole–Pulling Out

DRILLING BITS

RR–Rerun Bits

Rm–Reaming Bits for Core Hole

–Diamond Drilling

–Diamond Coring

CALIPER LOG

Hole enlargement Greater than 1½ times bit size

DASCO Chart Fig. #6
OPERATOR U. S. ARMY CORPS OF ENGINEERS
WELL Rocky Mtn. Arsenal Disposal #1
LOC: Sec. 26 T 2S R 67W
Spot Loc.: C NW NE
Adams County, Colorado
Elev.: GR 5203' KB

TIME ANALYSIS

From Spud Date to Total Depth

Items:	Days	%
Drilling on bottom	37.4	20.2
Coring on bottom	12.1	6.5
(1) Rotating progress	49.5	26.7
(Percent of Net Drlg. 51.7 %)		
Drill trips, rig service, etc.	17.9	9.7
Core trips, rmg. hole, etc.	28.4	15.4
(2) Net Drilling progress	95.8	51.8
Mechanical downtime	6.3	3.4
Cond. hole Lost Circ., Mix Mud	31.5	17.0
Circ. samples, wait orders	2.7	1.5
Drill stem test (14)	13.6	7.4
Surveys: Elec. Log	4.1	2.2
Fishing	8.9	4.8
Rig up on spud date	0.2	0.1
Casing: ream, run, WOC, test	18.2	9.8
Bowen Basket Recovery	2.4	1.3
Spinner Survey	0.7	0.4
Injectivity Test	0.6	0.3
(3) Overall time to T. D.	185.0	100.0

Operations After Reaching T. D.	Days
Cond. Hole; Lost Circ.; Mix Mud	5.3
Set 5½" Casing & Liner	4.8
Wait On Orders & Rig Repair	0.7
Lane Wells Logging	0.5
Injection Tests	1.6
Acidizing	0.9
Blowing Hole	3.5
Total Time After T. D.	17.3

MUD ADDITIVES

Additive	Lbs./Day (HUNDREDS)	Quantity (Lbs.-Sks)	Lbs./ft. of Hole
Bentonite	30.2	558,000 lbs.	46.3
Zeogel	6.0	111,700 lbs.	9.3
Baroco	7.7	141,900 lbs.	11.8
Baroid	7.1	132,100 lbs.	11.0
Q-Broxin	3.7	68,150 lbs.	5.7
Lime	3.6	65,700 lbs.	5.5
Drispose	1.6	29,050 lbs.	2.4
Caustic	0.3	5,800 lbs.	0.5
Salt	0.8	14,800 lbs.	1.2
Starch	0.8	14,100 lbs.	1.2
Starch Preservative	0.8	14,600 lbs.	1.2
Tannex	0.2	4,600 lbs.	0.4
Carbonox	0.1	1,500 lbs.	0.1
Barafos	-	50 lbs.	-
Soda Ash	0.1	2,300 lbs.	0.2

DRILLING ANALYSIS SERVICE CO.

C. A. Johnson Bldg., Denver, Colorado

September, 1961

20" CSG.

13 3/8" CSG. @ 2000' w/1800 SKS.

PACKER FOR 5" TUBING SET @ 8796'

9 5/8" CSG. @ 11,[illegible]' w/3360 SKS. (50-50 POZMIX)

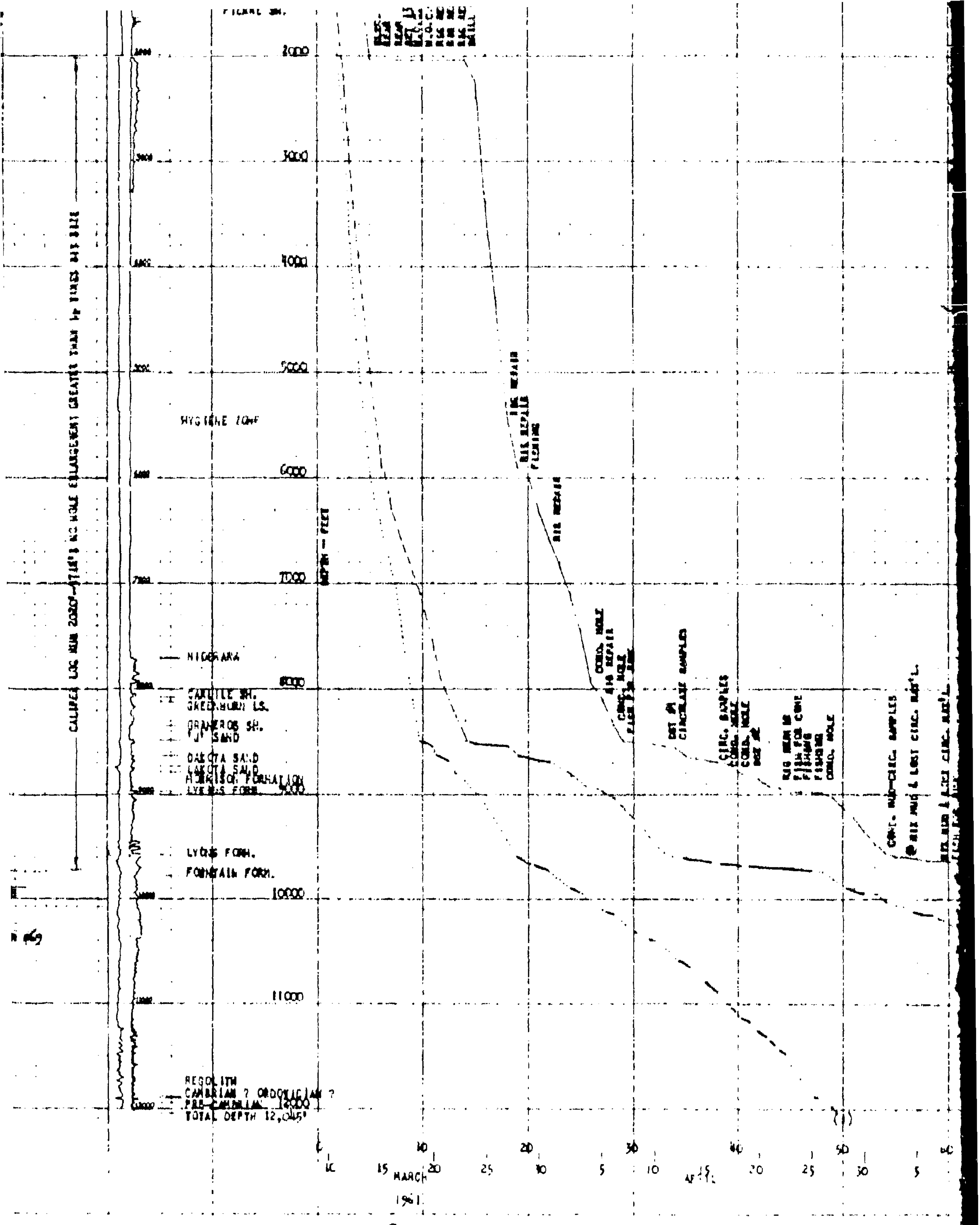
5" LINER FROM 11,007' TO 11,975' w/250 SKS.

9.1	31		330	500	6-8" DC
8.5	35	10.0	460	800	9-7" DC
9.0	34	7.2	460	1600	6-8" & 9-7" DC
9.4	32	7.8	460	900	6-8" & 9-7" DC
9.4	33	9.4	460	1000	6-8" & 12-7" DC
9.2	[illegible]	9.0	[illegible]	1100	6-8" & 21-7" DC
9.5	33	9.0	460	1150	
9.4	33	9.0	500	1000	
9.4	33	8.0	460	1300	6-8" DC & 21-7" DC
9.4	33	9.0	500	1300	
9.3	32	9.2	460	1300	
9.5	37	7.0	500	1300	
					6-8" & 21-7" DC
9.5	33	8.3	500	1400	
9.8	60	6.8	500	1200	
9.6	78	5.8	500	1400	
9.5	58	5.5	500	1375	14-8" & 21-7" DC
9.2	52	7.0	500	1300	
9.4	56	8.7	500	1300	
9.8	56	7.4	500	1300	14-8" & 21-7" DC
9.7	61	9.6	460	1200	5-8" & 21-7" DC
			420	1300	
9.5	89	7.1	310	1000	
9.3	117	7.2	420	900	6-8" & 21-7" DC
9.3	80	7.0	480	1200	
9.3	68	8.0	420	700	
9.5	72	6.3	370	800	6-8" & 21-7" DC
9.8	56	5.8	260	900	
8.7	40	7.7	280	1050	80-4½" DC
8.8	45	7.2	240	1150	
9.0	43	7.2	260	1500	
9.0	43	5.8	220	2000	80-4½" DC

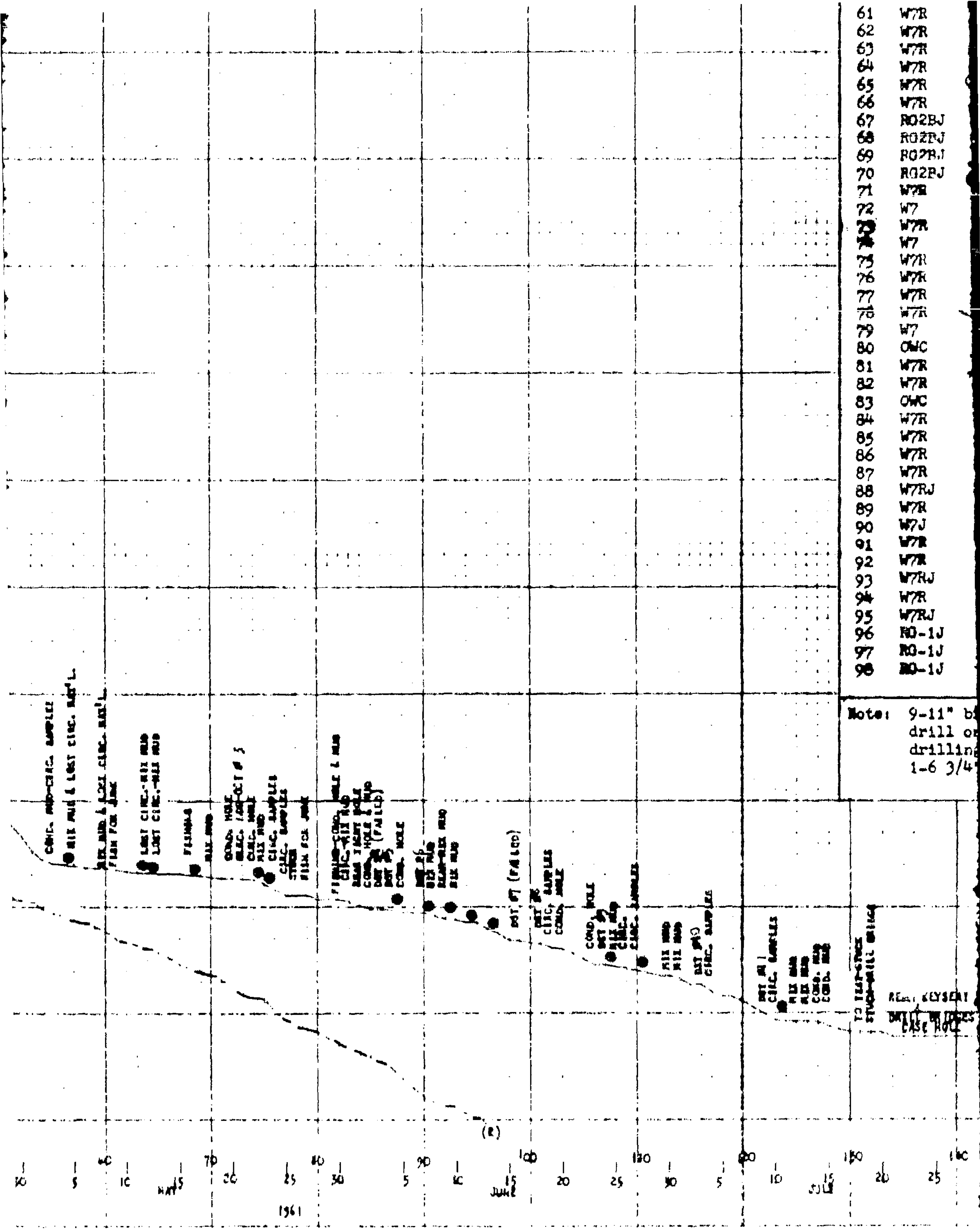
5 10 15 20 25 30 35 40 55 60 70 75 80 85 90 95

MR #51 MR #57 MR #69 MR #56 MR [illegible]

CALIPER LOG RUN 2020'–9718'; NO HOLE ENLARGEMENT GREATER THAN 4" TIMES BIT SIZE


CALIPER LOG RUN 2020'-9718'; NO HOLE ENLARGEMENT GREATER THAN 1½ TIMES BIT SIZE
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
DEPTH - FEET
HYGIENE ZONE
NIOBRARA
CARLILE SH.
GREENHORN LS.
GRANEROS SH.
"J" SAND
DAKOTA SAND
LAKOTA SAND
MORRISON FORMATION
LYKINS FORM.
LYONS FORM.
FOUNTAIN FORM.
REGOLITH
CAMBRIAN ? ORDOVICIAN ?
PRE-CAMBRIAN
TOTAL DEPTH 12,045'
RIG REPAIR
FISHING
CORE HOLE
CIRCULATE SAMPLES
CIRC. SAMPLES
FISH FOR CONE
LOST CIRC.
10
20
30
40
50
60
15
25
5
MARCH
1961

G1



61	W7R
62	W7R
63	W7R
64	W7R
65	W7R
66	W7R
67	RO2BJ
68	RO2BJ
69	RO2BJ
70	RO2BJ
71	W7R
72	W7
73	W7R
74	W7
75	W7R
76	W7R
77	W7R
78	W7R
79	W7
80	OWC
81	W7R
82	W7R
83	OWC
84	W7R
85	W7R
86	W7R
87	W7R
88	W7RJ
89	W7R
90	W7J
91	W7R
92	W7R
93	W7RJ
94	W7R
95	W7RJ
96	RO-1J
97	RO-1J
98	RO-1J

Note: 9-11" b[illegible]
drill o[illegible]
drilling[illegible]
1-6 3/4"[illegible]

H

W7R		14	OSC3
W7R		15	TT3
W7R		16	DT20
W7R		17	K2P
W7R		18	W7R
RG2BJ	7/8"	19	W7R
RG2BJ	7/8"	20	W7R
RG2BJ	7/8"	21	OWSV
RG2PJ	7/8"	22	W7R
W7R		23	W7R
W7		24	W7R
W7R		25	T2
W7		26	W7R
W7R		27	W7
W7R		28	YM
W7R		29	C2
W7R		30	OWC
W7		31	W7R
OWC		32	W7R
W7R		33	W7R
W7R		34	OWC
OWC		35	C2
W7R		36	OSC10
W7R		37	OSC10
W7R		38	OSC10
W7R		39	YTL
W7RJ	3/8"	40	OWS
W7R		41	T2
W7J	3/8"	42	W7R
W7R		43	W7R
W7R		44	2C
W7RJ	3/8"	45	W7R
W7R		46	W7R
W7RJ	3/8"	47	W7R
RG-1J	3/8"	48	W7R
RG-1J	3/8"	49	W7R
RG-1J	3/8"	50	W7R
		51	W7R

te: 9-11" bits to condition hole, drill on junk, ream bridges and drilling cement.
1-6 3/4" bit used to drill junk.

Swivel National R3-2 3/4" I.D Hose 3" x 55'

WATER SOURCE

BIT SUMMARY

Size	No. Bits	Footage	No Hours	Feet/Hour	Feet/Bit	Hrs On Bot/Bit
DRILLING						
12 1/4"	3	2030	46.2	43.9	677	15.4
11"	62.2	8711	710.6	12.2	140	11.4
6 3/4"	14.5	665	139.5	4.8	46	9.6
REAMING						
24"	1	138	4.0	34.5	138	4.0
17 1/4"	2	1892	34.2	55.6	946	17.1
11"	17.8	520	138.0	3.8	29	7.7
6 3/4"	0.5	146	6.7	21.8	292	13.4
DIAMOND CORING						
8 7/8"	3	191	100.5	1.9	-	-
8 9/16"	1	18	9.5	1.9	-	-
7 13/16"	2	282	130.2	2.2	-	-
6 11/16"	3	142	51.2	2.8	-	-
Dia. Bowen Basket 6	-	-	-	-		

LEGEND

DRILLING CURVES

——— Overall Drilling Progress Curve

——— Net Drilling Progress Curve (Includes only time on bottom, normal trips, connections, drift surveys, rig service, normal mud mixing, i. e. related to normal drilling progress.)

. . . . . . Rotating Progress Curve

Coring

Diamond Drilling

Red Arrow: Highlights hazards

● Lost Circulation Occurence Including mixing L. C. mud

◆ Spot Lost Circulation, Cement Plug

▼ Cleanout Difficulties—Trip In

▲ Tight Hole—Pulling Out

DRILLING BITS

RR—Rerun Bits

Rm—Reaming Bits for Core Hole

—Diamond Drilling

—Diamond Coring

CALIPER LOG

Hole enlargement Greater than 1½ times bit size

DRILLING ANALYSIS SERVICE CO.

C. A. Johnson Bldg., Denver, Colorado

September, 1961

Items

Drilling on botto

Coring on bottor

(1) Rotating p

(Percent of

Drill trips, rig ser

Core trips, rmg. H

(2) Net Drillin

Mechanical dow

Cond. hole Los

Circ. samples, wa

Drill stem test (

Surveys: Elec.

Fishing

Rig up on spud c

Casing: ream, ru

Bowen Basket H

Spinner Survey

Injectivity Te

(3) Overall tin

Opera

Cond. Hole; Lo

Set 5½" Casing

Wait On Orders

Lane Wells Log

Injection Test

Acidizing

Blowing Hole

Total Time After

Additive

Bentonite

Zeogel

Baroco

Baroid

Q-Broxin

Lime

Driscose

Caustic

Salt

Starch

Starch Preserv

Tannex

Carbonox

Barafos

Soda Ash

Condet

Defoamer

Fibertex

Cottonseed Hu

Plug-git

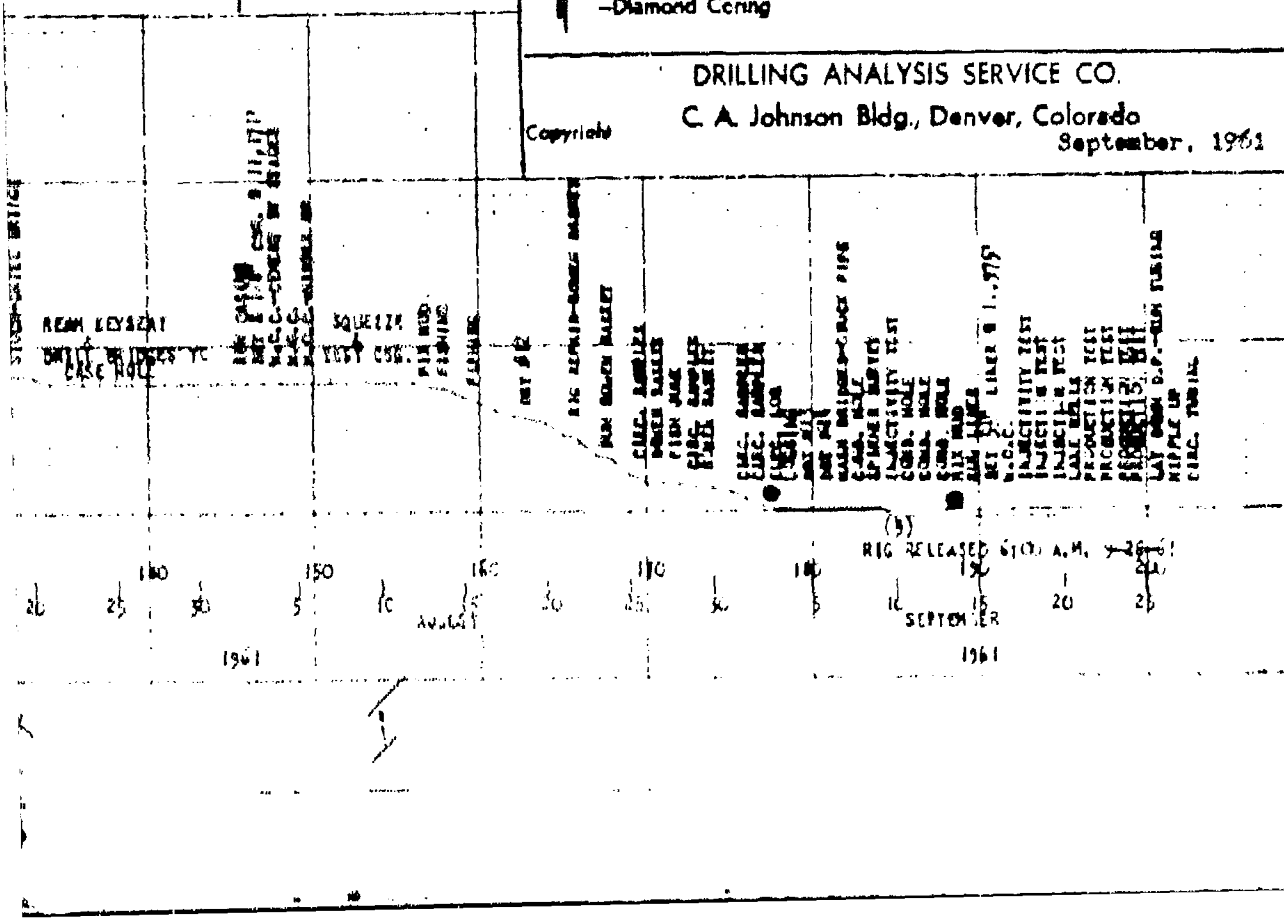
Jelflake

Polyflake

Cello Flake

Micatex

Total



TER SOURCE:

BIT SUMMARY

	No. Bits	Footage	No. Hours	Feet/ Hour	Feet/ Bit	Hrs On Bot/Bit
			DRILLING			
4"	3	2090	46.2	43.9	677	15.4
	62.2	8711	710.6	12.2	140	11.4
4"	14.5	665	139.5	4.8	46	9.6
			REAMING			
	1	138	4.0	34.5	138	4.0
4"	2	1892	34.2	55.6	946	17.1
	17.8	520	138.0	3.8	29	7.7
4"	0.5	146	6.7	21.8	292	13.4
			DIAMOND	**CORING**		
8"	3	191	100.5	1.9	-	-
16"	1	18	9.5	1.9	-	-
/16"	2	282	130.2	2.2	-	-
/16"	3	142	51.2	2.8	-	-
Bowen Basket 6			-	-	-	-

LEGEND

ING CURVES

- Overall Drilling Progress Curve
- Net Drilling Progress Curve (Includes only time on bottom, normal trips, connections, drift surveys, rig service, normal mud mixing, i. e. related to normal drilling progress)
- . . . Rotating Progress Curve
- Coring
- Diamond Drilling
- Red Arrow: Highlights hazards
- Lost Circulation Occurence Including mixing L. C. mud
- Spot Lost Circulation, Cement Plug
- Cleanout Difficulties—Trip In
- Tight Hole—Pulling Out

ING BITS

RR—Rerun Bits

Rm—Reaming Bits for Core Hole

-Diamond Drilling

-Diamond Coring

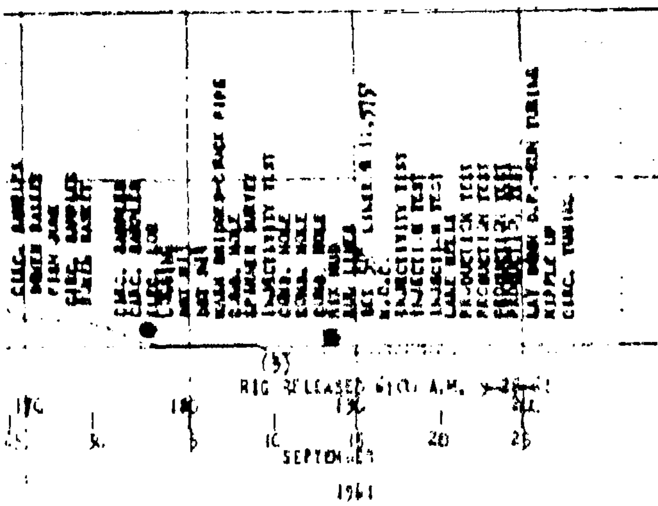
CALIPER LOG

Hole enlargement Greater than 1½ times bit size

DRILLING ANALYSIS SERVICE CO.

C. A. Johnson Bldg., Denver, Colorado

September, 1961



Items:	Days	%
Drilling on bottom	37.4	20.2
Coring on bottom	12.1	6.5
(1) Rotating progress (Percent of Net Drlg. 51.7 %)	49.5	26.7
Drill trips, rig service, etc	17.9	9.7
Core trips, rmg. hole, etc.	28.4	15.4
(2) Net Drilling progress	95.8	51.8
Mechanical downtime	6.3	3.4
Cond. hole Lost Circ., Mix Mud	31.5	17.0
Circ. samples, wait/orders	2.7	1.5
Drill stem test (19)	13.6	7.4
Surveys: Elec. Log	4.1	2.2
Fishing	8.7	4.8
Rig up on spud date	0.2	0.1
Casing: ream, run, WOC, test	18.2	9.8
Bowen Basket Recovery	2.4	1.3
Spinner Survey	0.7	0.4
Injectivity Test	0.6	0.3
(3) Overall time to T. D.	185.0	100.0

Operations After Reaching T. D.	Days
Cond. Hole; Lost Circ.; Mix Mud	5.3
Set 5½" Casing & Liner	4.8
Wait On Orders & Rig Repair.	0.7
Lane Wells Logging	0.5
Injection Tests	1.6
Acidizing	0.9
Blowing Hole	3.5
Total Time After T. D.	17.3

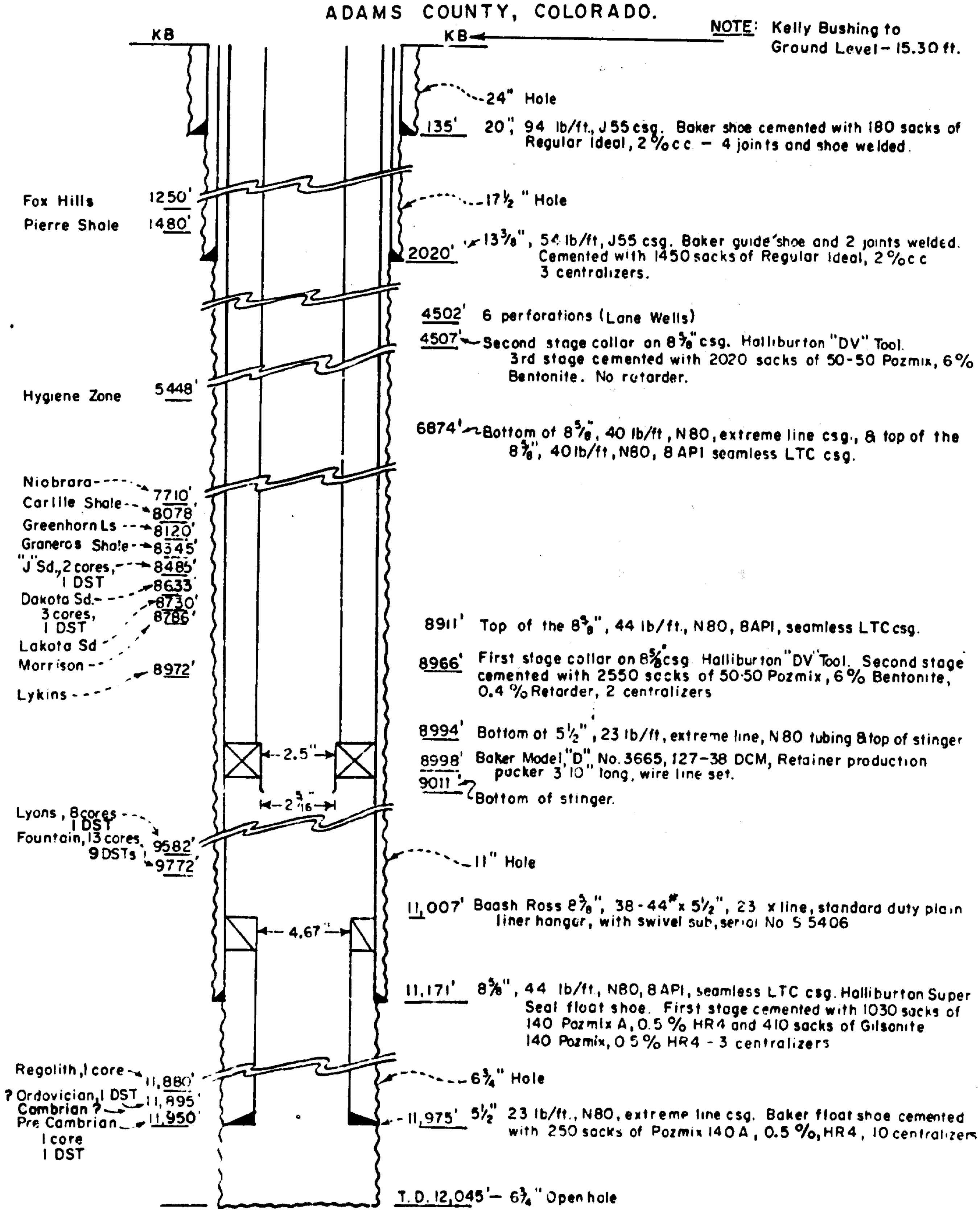
MUD ADDITIVES

Additive	Lbs/Day (PUNDPOS)	Quantity (Lbs.-Sks)	Lbs./Ft. of Hole
Bentonite	30.2	558,000 lbs.	46.3
Zeogel	6.0	111,700 lbs.	9.3
Surfco	7.7	141,900 lbs.	11.8
Baroid	7.1	132,100 lbs.	11.0
Q-Broxin	3.7	68,150 lbs.	5.7
Lime	3.6	65,700 lbs.	5.5
Driscose	1.6	29,050 lbs.	2.4
Caustic	0.3	5,800 lbs.	0.5
Salt	0.8	14,800 lbs.	1.2
Starch	0.8	14,100 lbs.	1.2
Starch Preservative	0.8	14,600 lbs.	1.2
Tannex	0.2	4,600 lbs.	0.4
Carbonox	0.1	1,500 lbs.	0.1
Barafos	-	50 lbs.	-
Soda Ash	0.1	2,300 lbs.	0.2
Condet	-	440 lbs.	-
Defoamer	-	165 lbs.	-
Fibertex	2.5	46,500 lbs.	3.9
Cottonseed Hulls	1.2	22,000 lbs.	1.8
Plug-git	1.8	33,750 lbs.	2.8
Jelflake	0.6	11,050 lbs.	0.9
Polyflake	0.3	6,350 lbs.	0.5
Cello Flake	0.1	1,400 lbs.	0.1
Micatex	0.1	1,250 lbs.	0.1
Total	69.7	1,289,555 lbs.	107.1

CASING AND HOLE DETAILS

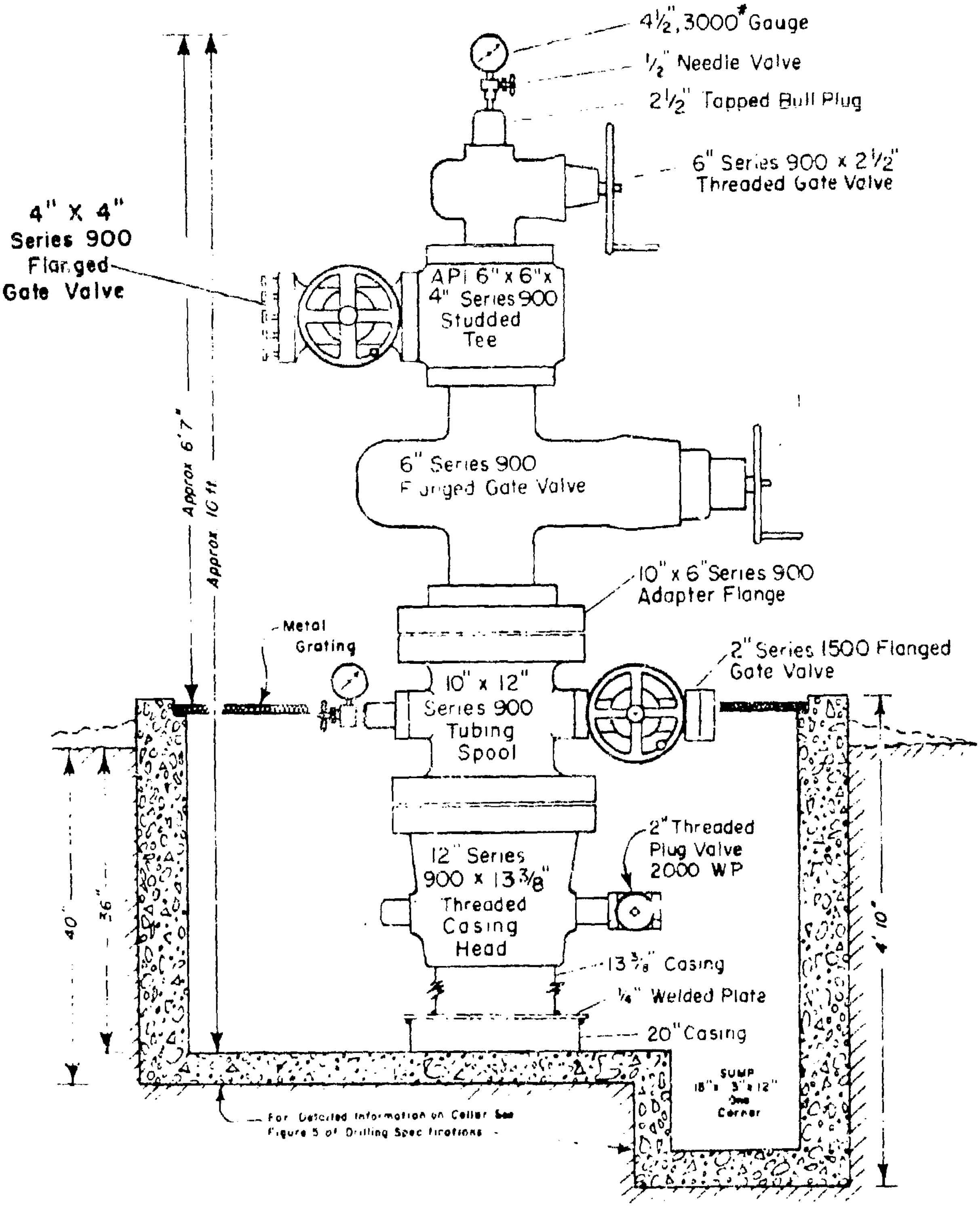
FIGURE 7

PRESSURE INJECTION DISPOSAL WELL
ROCKY MOUNTAIN ARSENAL
SECTION 26, T2S-R67W
ADAMS COUNTY, COLORADO.



E A Polumbus Jr And Associates, Inc

FIGURE 8



WELL HEAD INSTALLATION

3000# PSI W.P.
6000# T.P.

Drawing Schematic Only
Not to be scaled

E. A. POLUMBUS, JR. AND ASSOCIATES, INC.

FIGURE 9

BOWEN JUNK BASKET

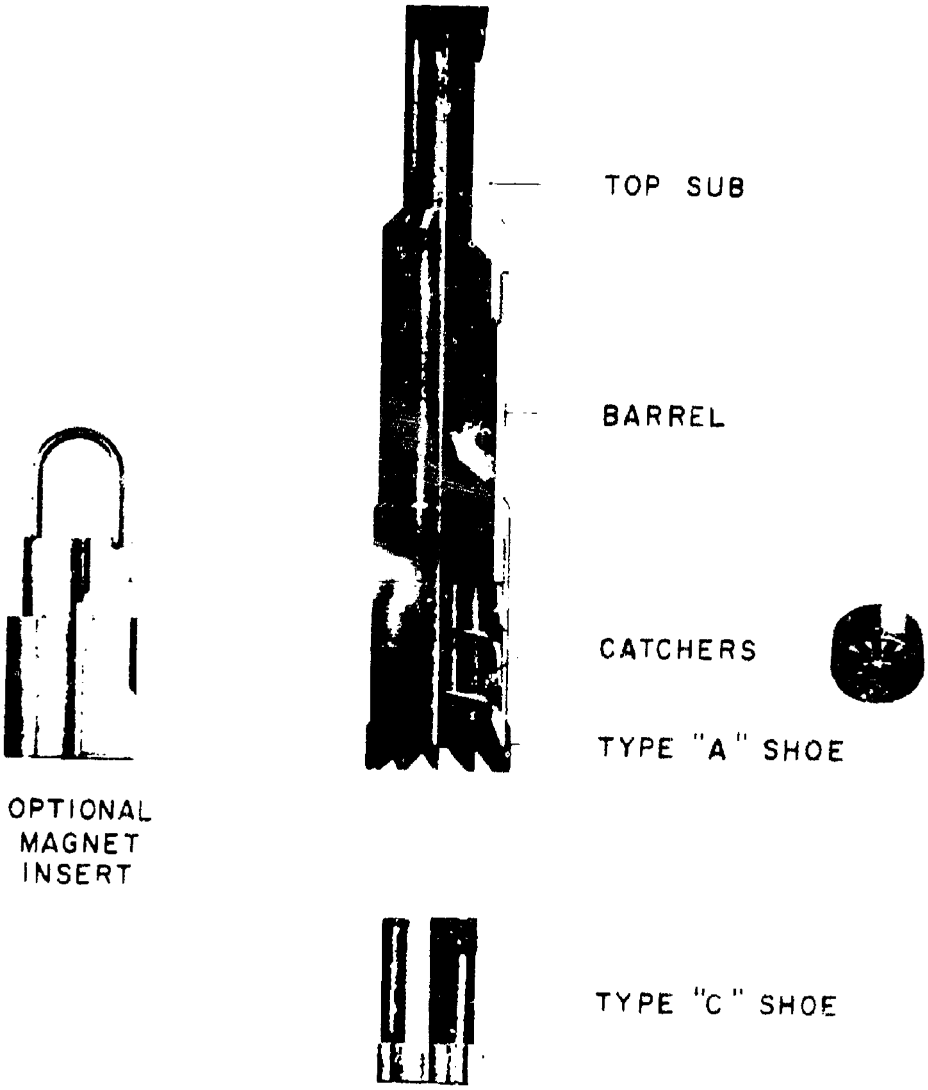
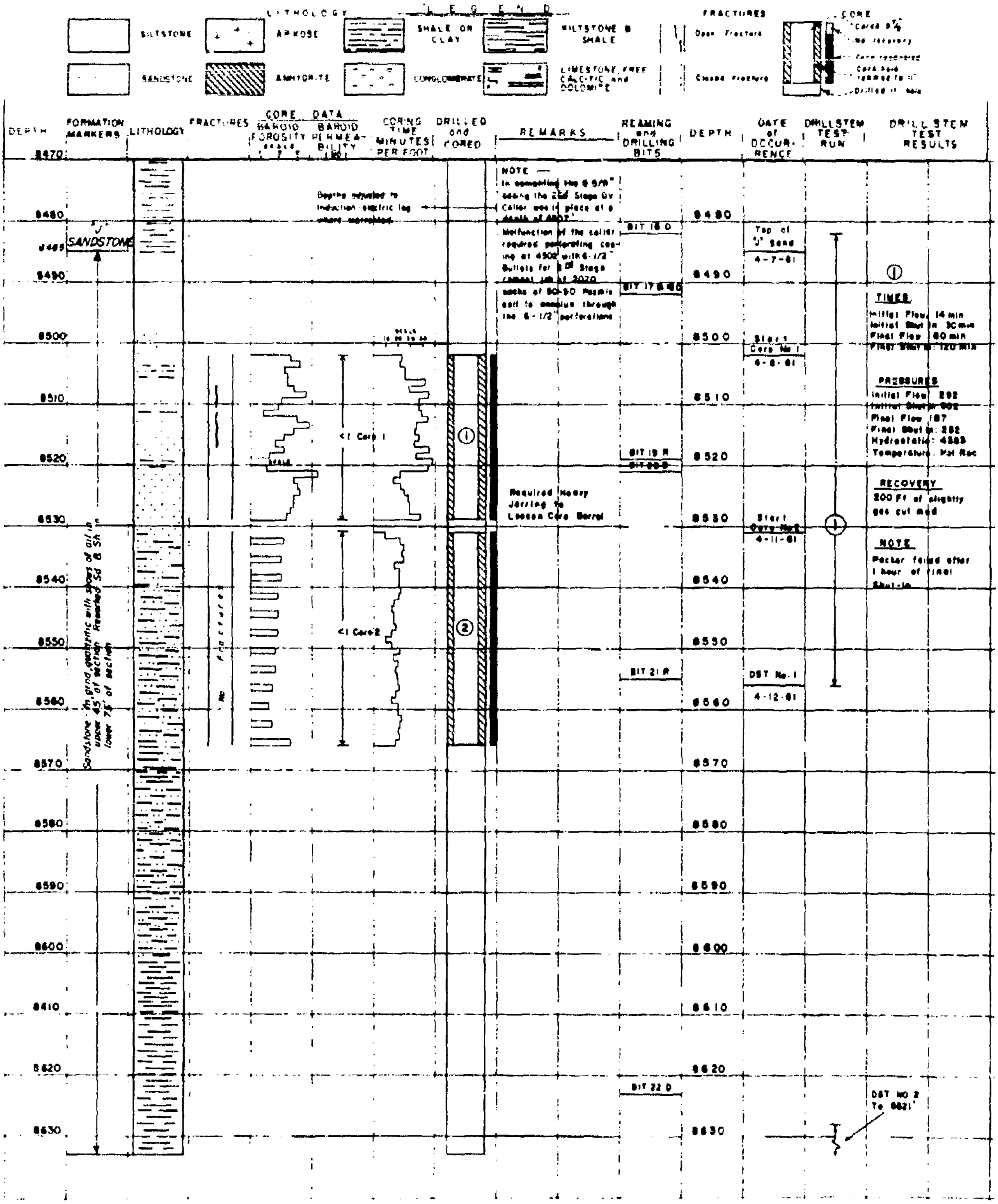


FIGURE 10

GRAPHICAL REPRESENTATION OF FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL PRESSURE INJECTION DISPOSAL WELL



GRAPHICAL REPRESENTATION OF
FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL

FIGURE 10

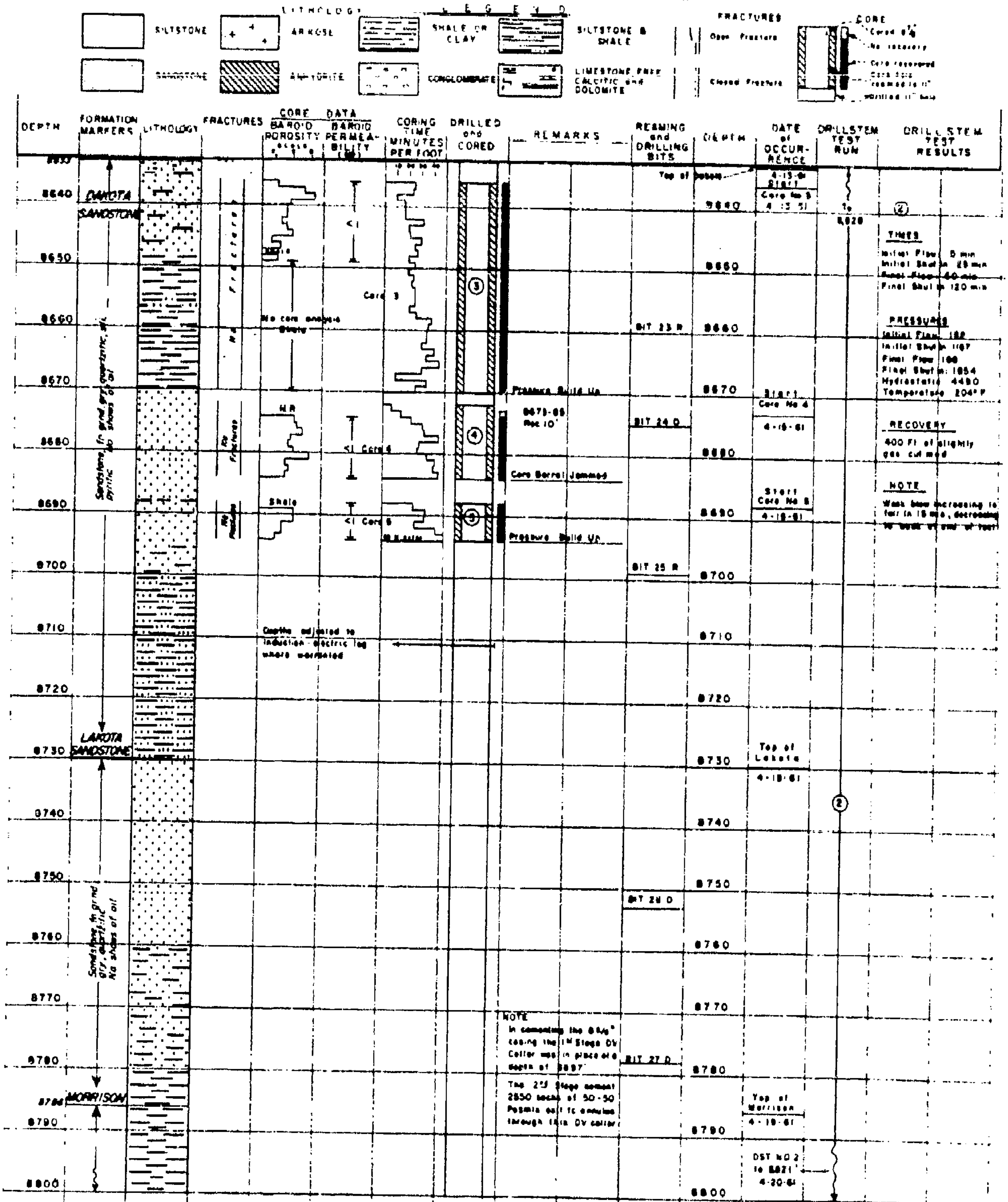
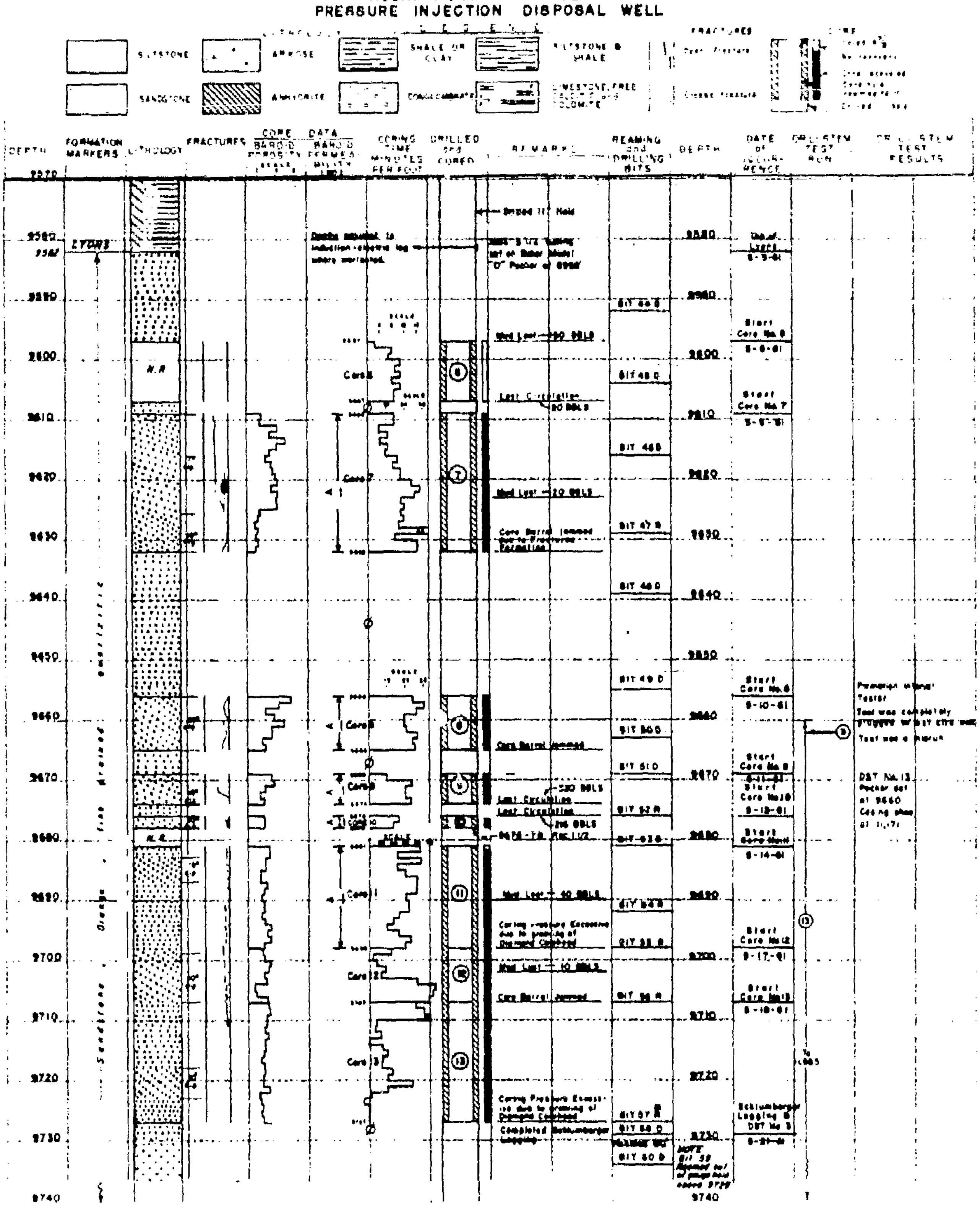


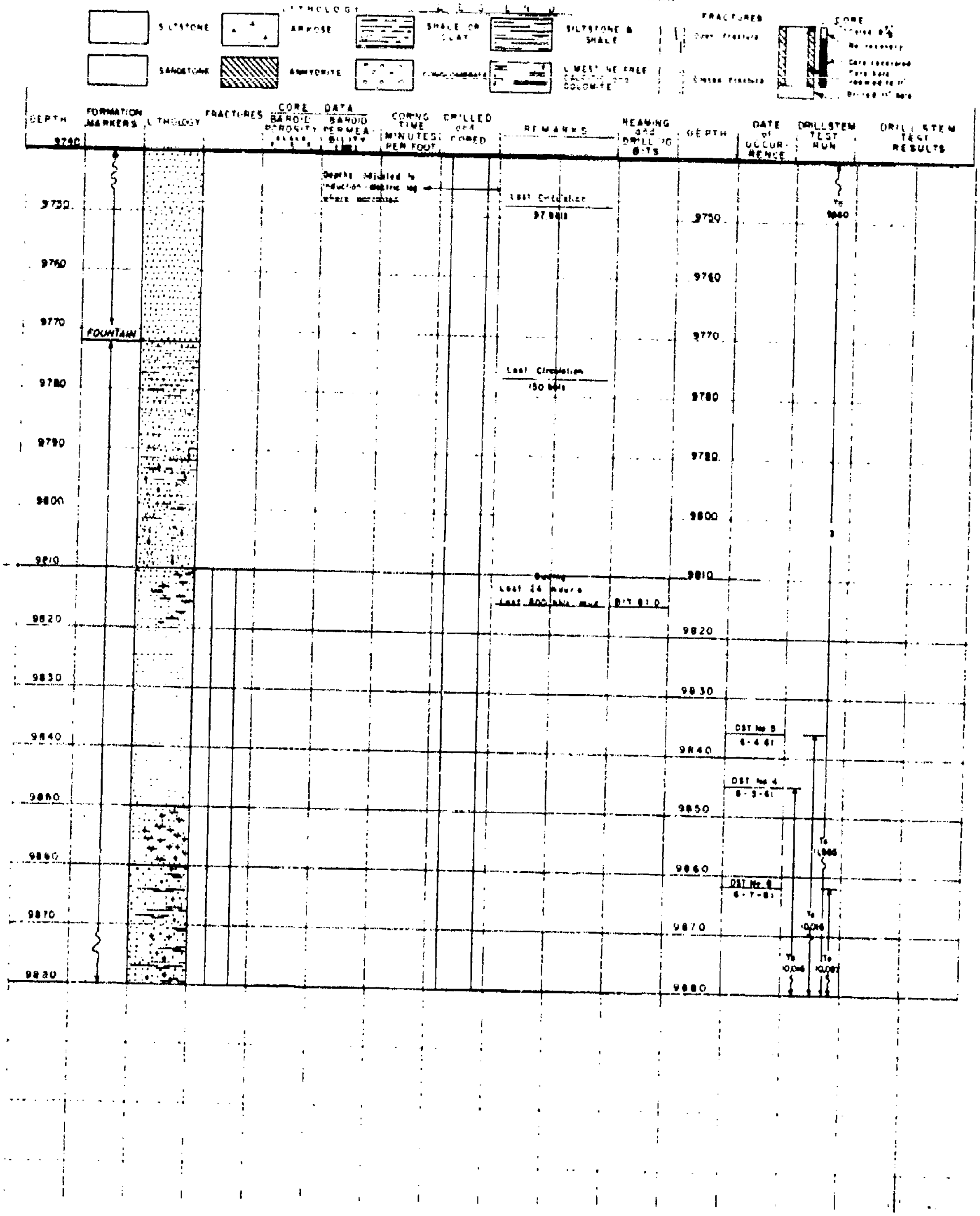
FIGURE 10.

GRAPHICAL REPRESENTATION OF FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL PRESSURE INJECTION DISPOSAL WELL



GRAPHICAL REPRESENTATION OF FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL

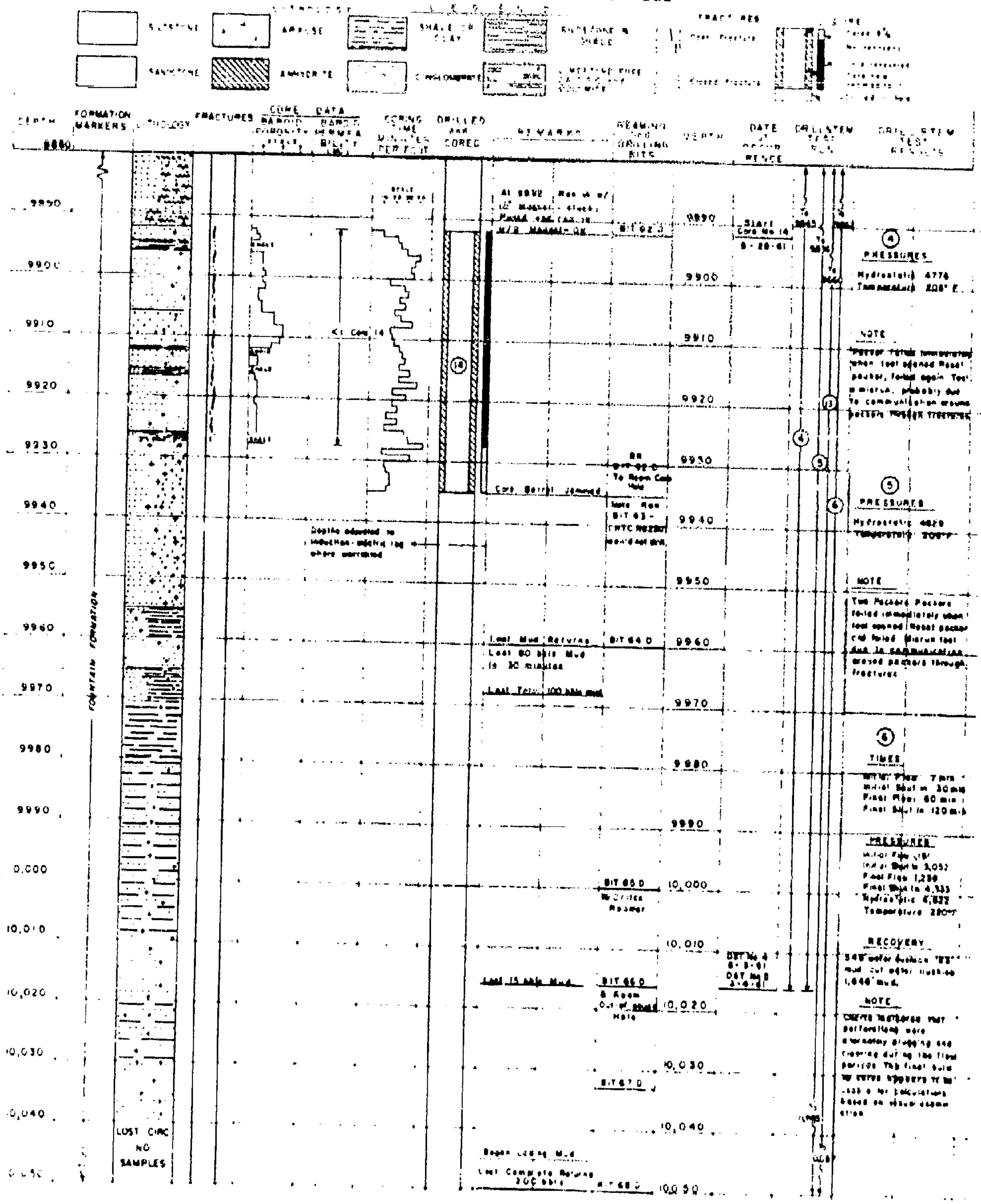
FIGURE 10.



E. A. POLUMBUS, JR. AND ASSOCIATES, INC.

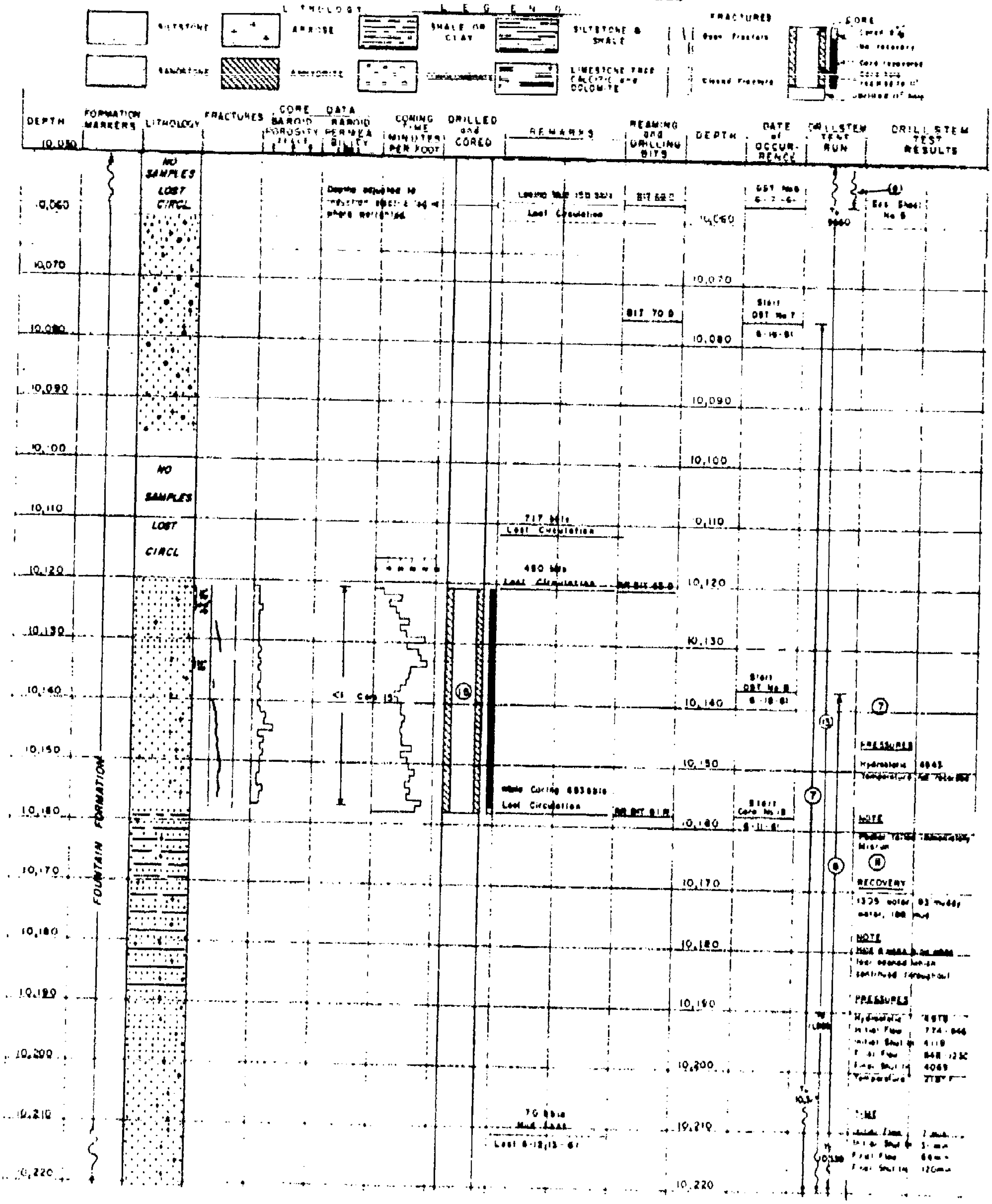
GRAPHICAL REPRESENTATION OF
FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL

FIGURE 10



NO. 8 **FIGURE 10.**
INTERVAL 10,060 - 10,220'

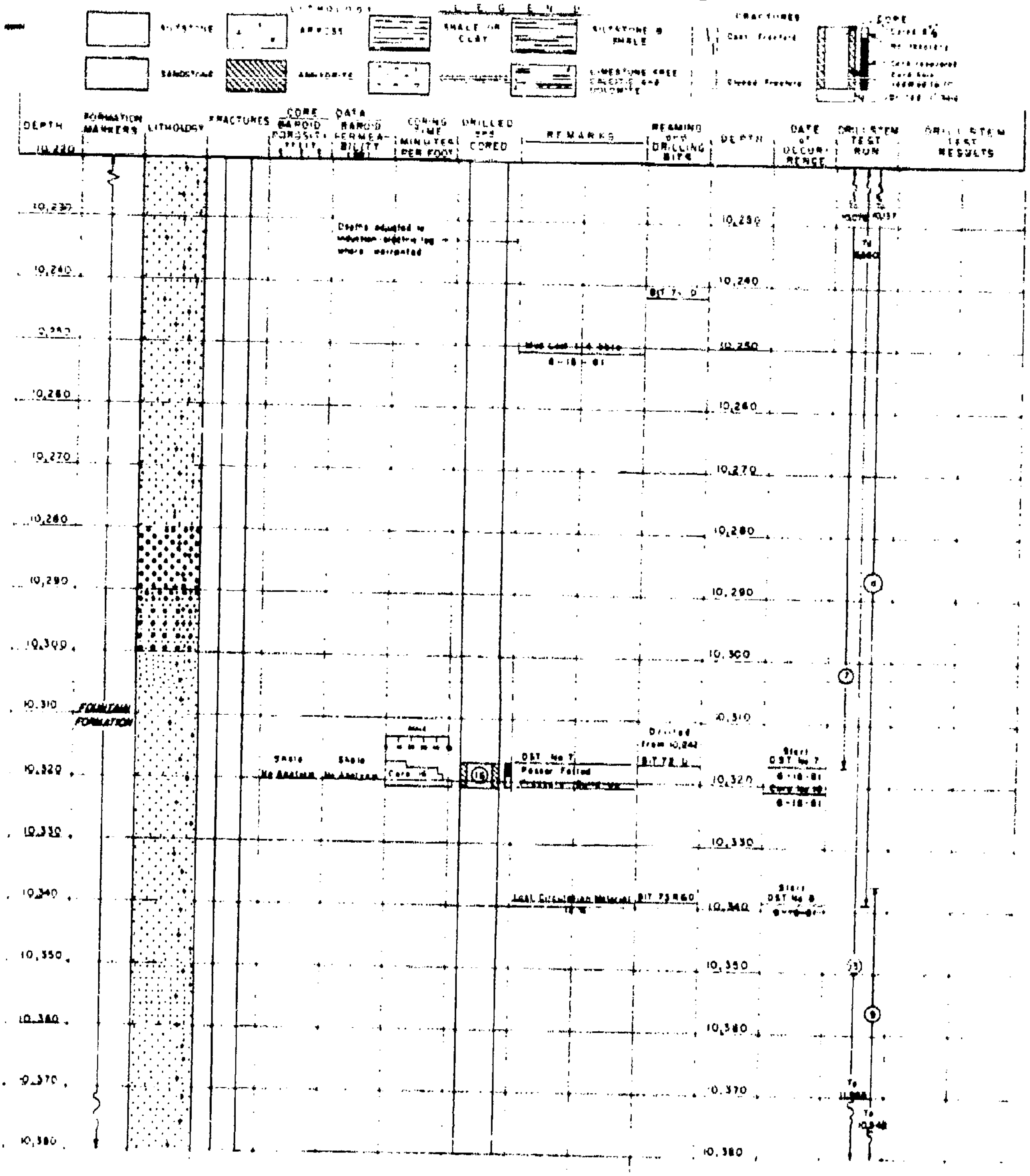
GRAPHICAL REPRESENTATION OF FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL PRESSURE INJECTION DISPOSAL WELL



L. A. [illegible] JR. AND ASSOCIATES, INC.

GRAPHICAL REPRESENTATION OF FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL PRESSURE INJECTION DISPOSAL WELL

FIGURE 10



E. A. POLUMBUS JR AND ASSOCIATES, INC

GRAPHICAL REPRESENTATION OF FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL PRESSURE INJECTION DISPOSAL WELL

FIGURE 10.

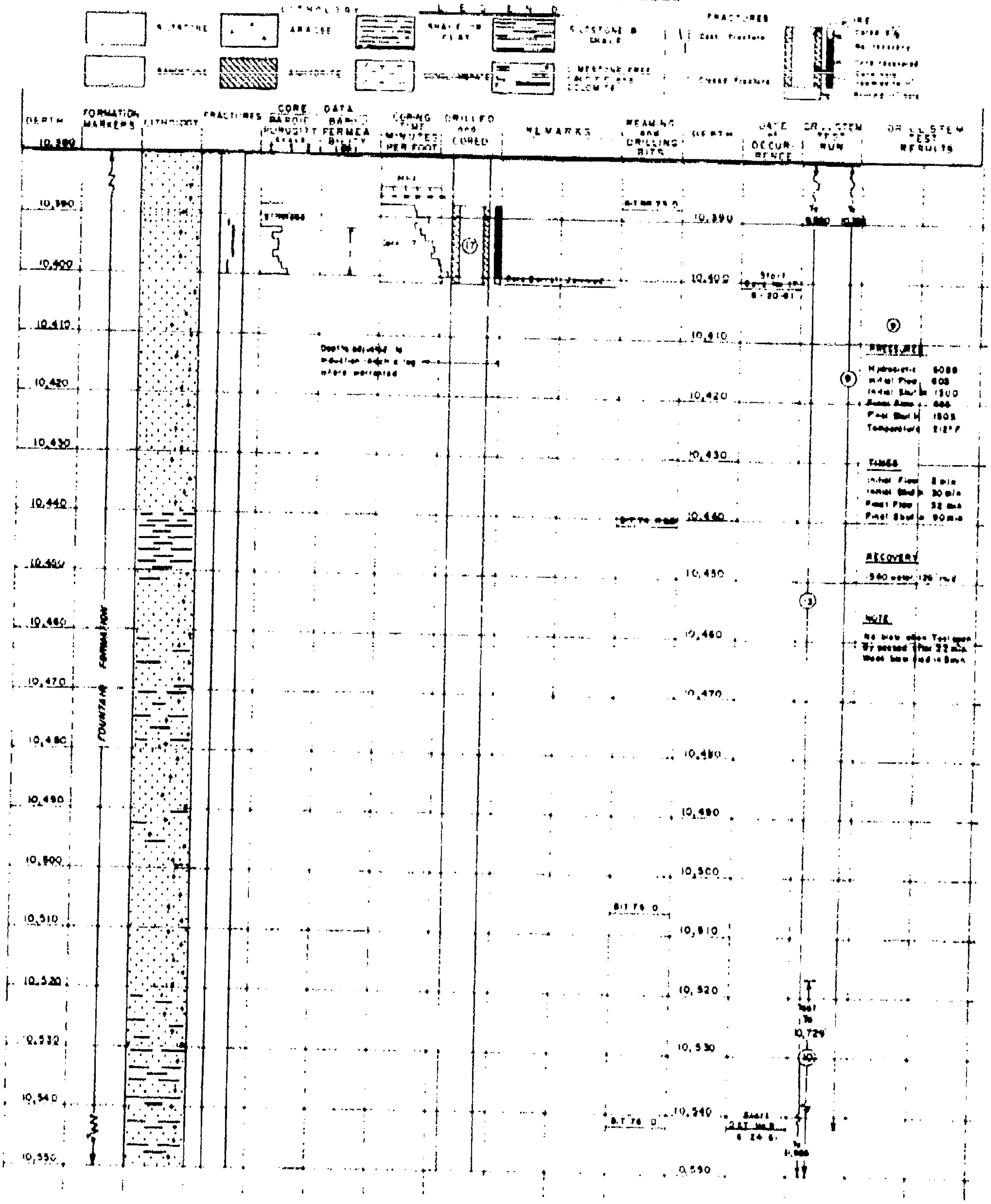
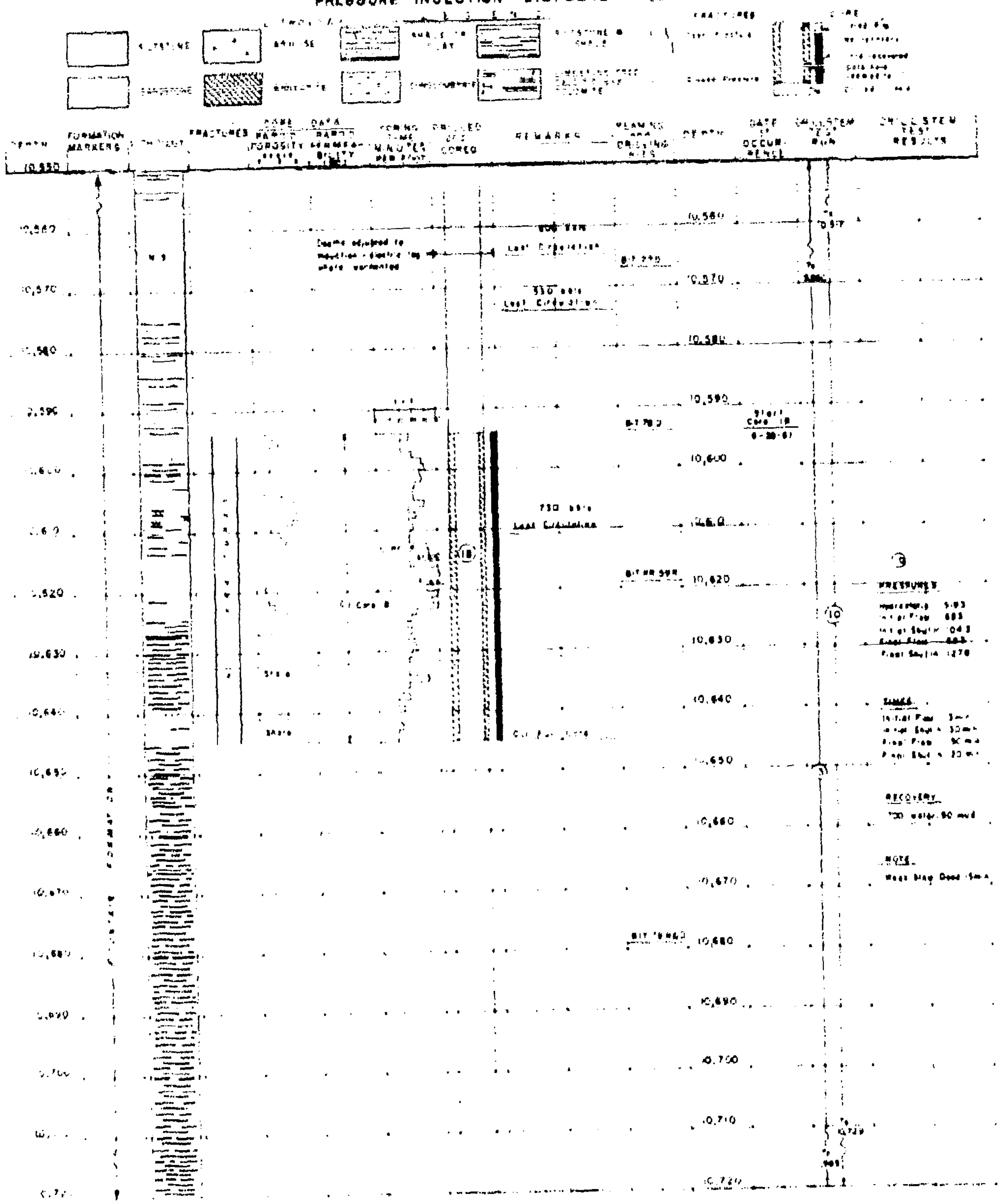


FIGURE 10

GRAPHICAL REPRESENTATION OF
FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL



GRAPHICAL REPRESENTATION OF FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL

FIGURE 10.

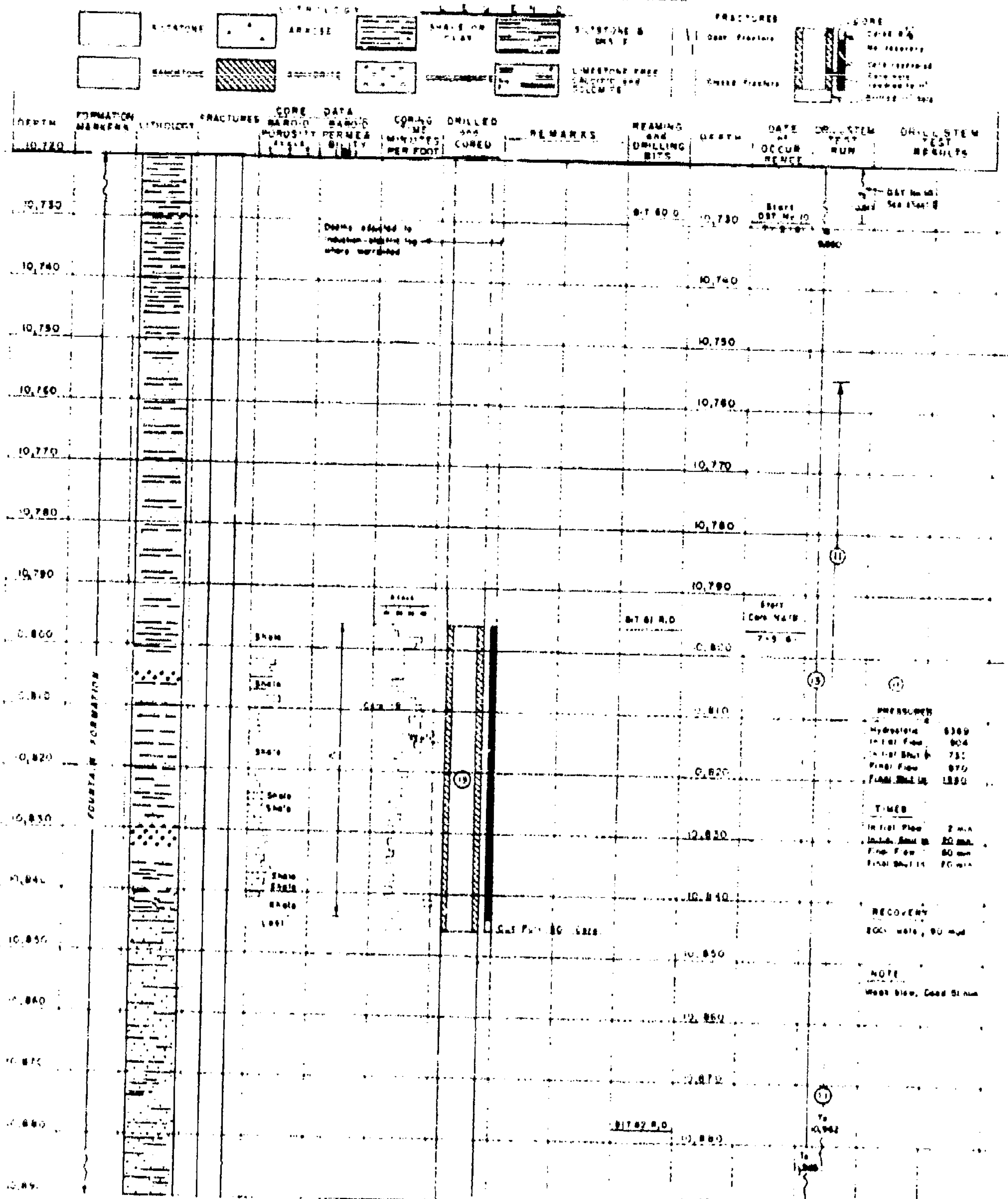
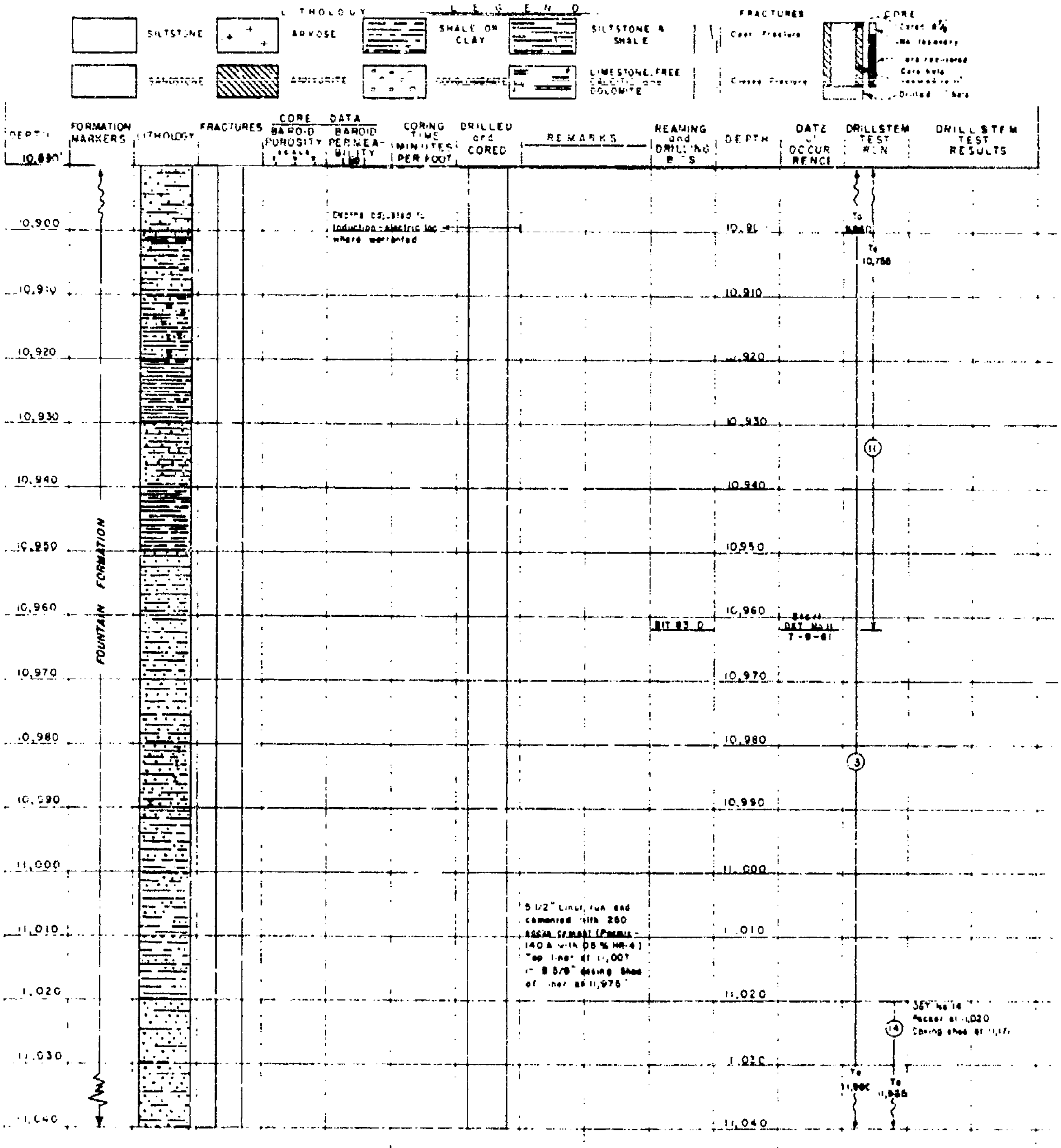


FIGURE 10.

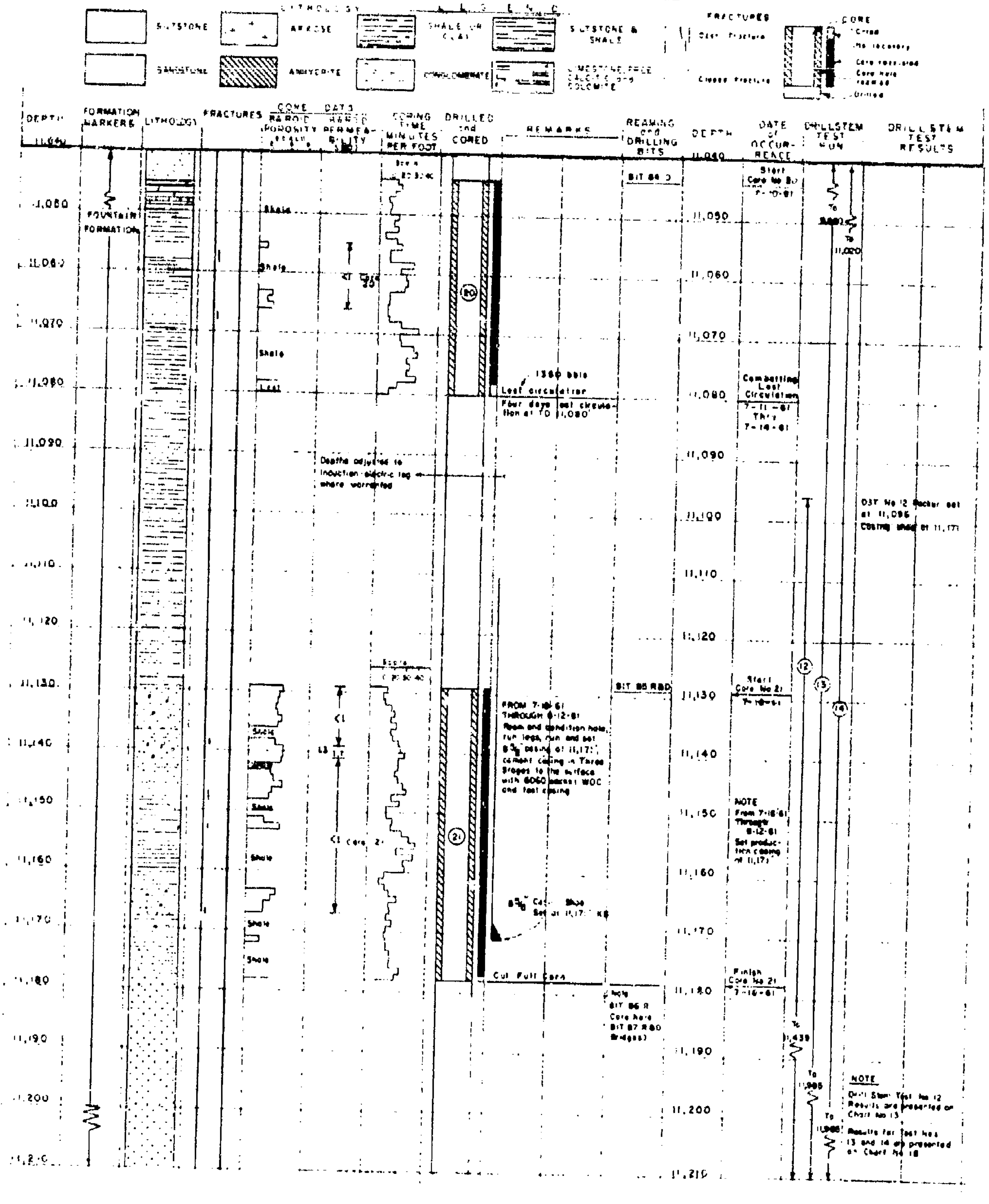
GRAPHICAL REPRESENTATION OF
FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL

INTERVAL 10,890-11,040



GRAPHICAL REPRESENTATION OF
FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL

FIGURE 10.



GRAPHICAL REPRESENTATION OF FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL PRESSURE INJECTION DISPOSAL WELL

FIGURE 10.

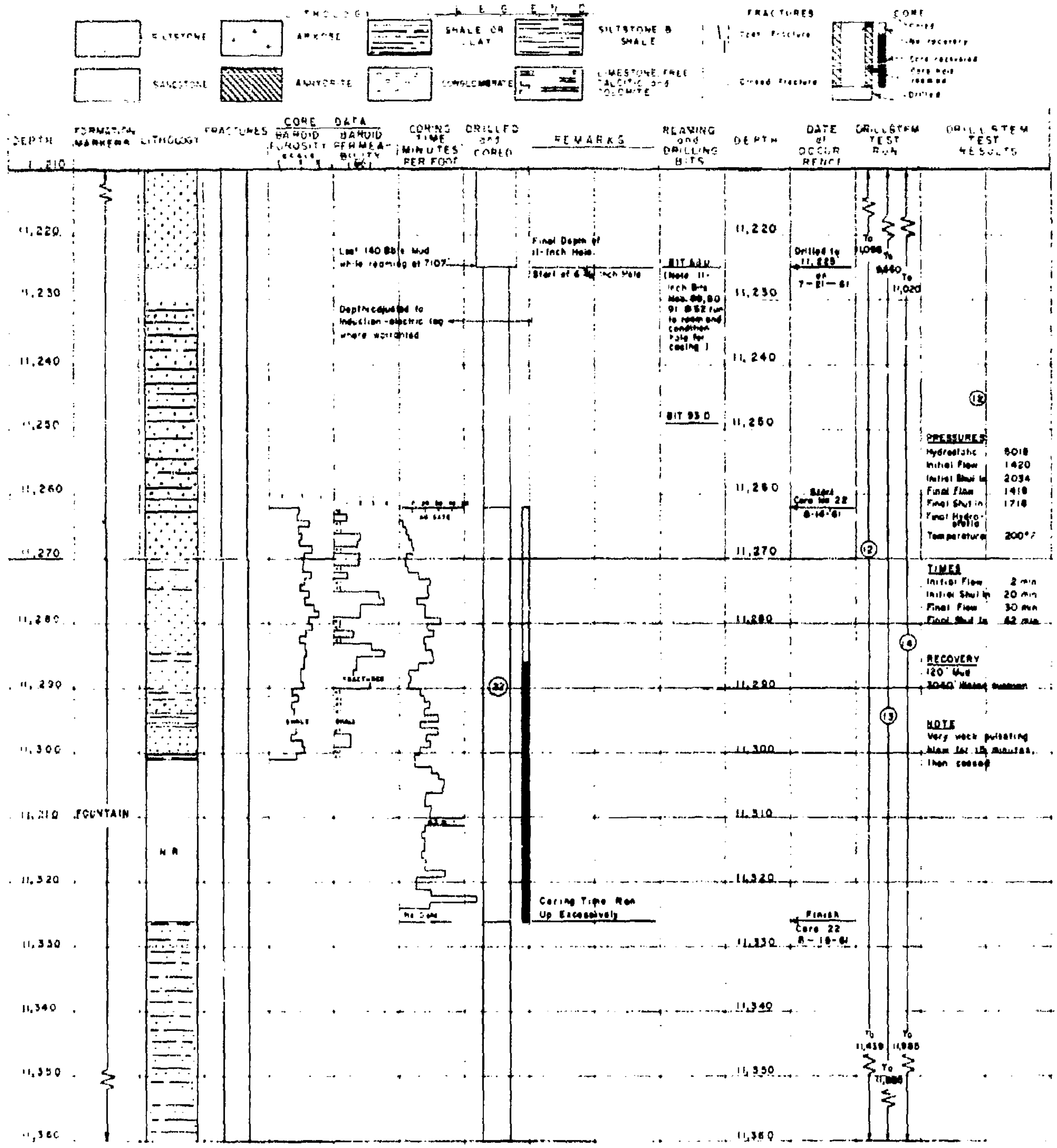
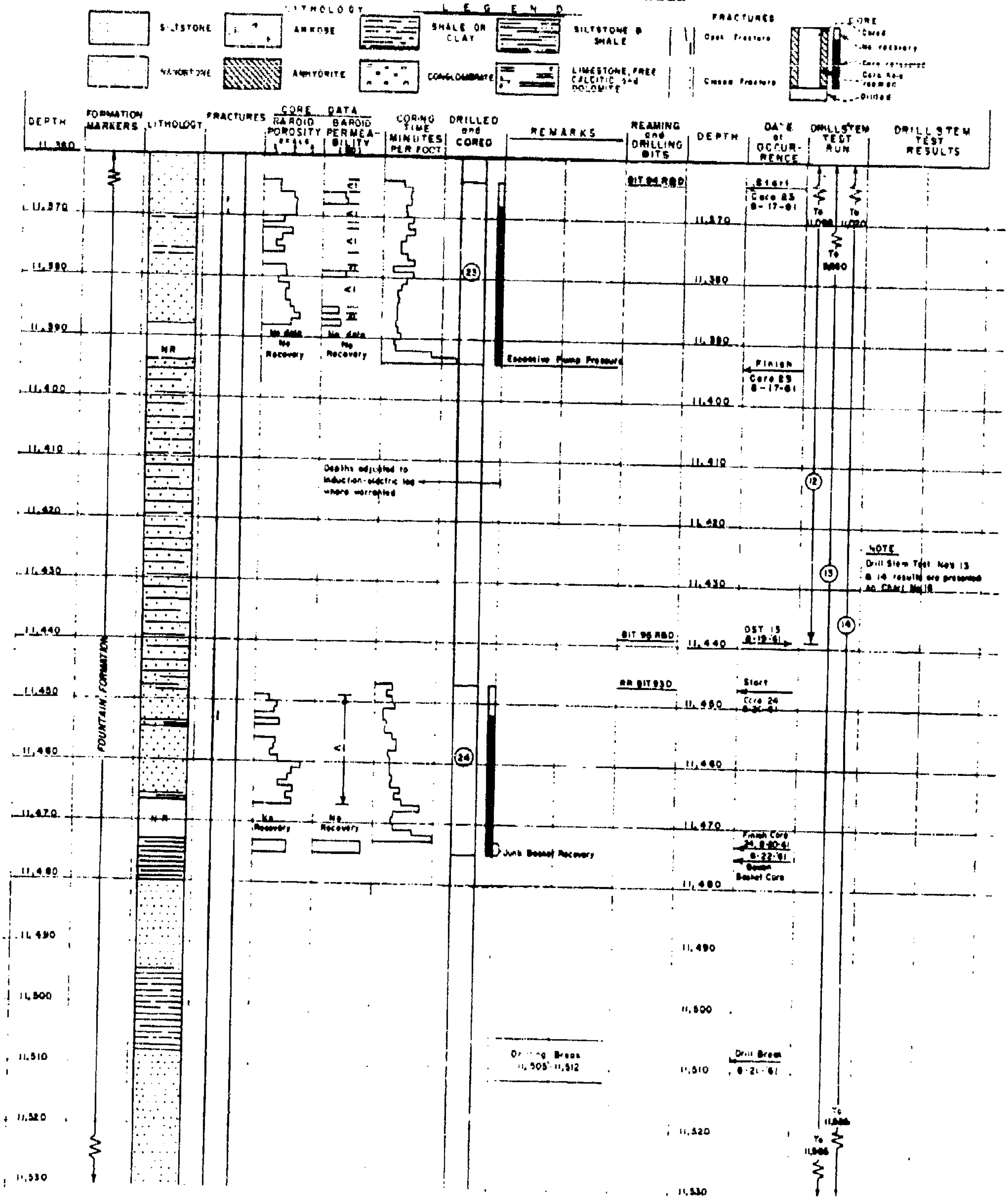


FIGURE 10.

GRAPHICAL REPRESENTATION OF FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL PRESSURE INJECTION DISPOSAL WELL

NO. 14
INTERVAL 11,360 - 11,530



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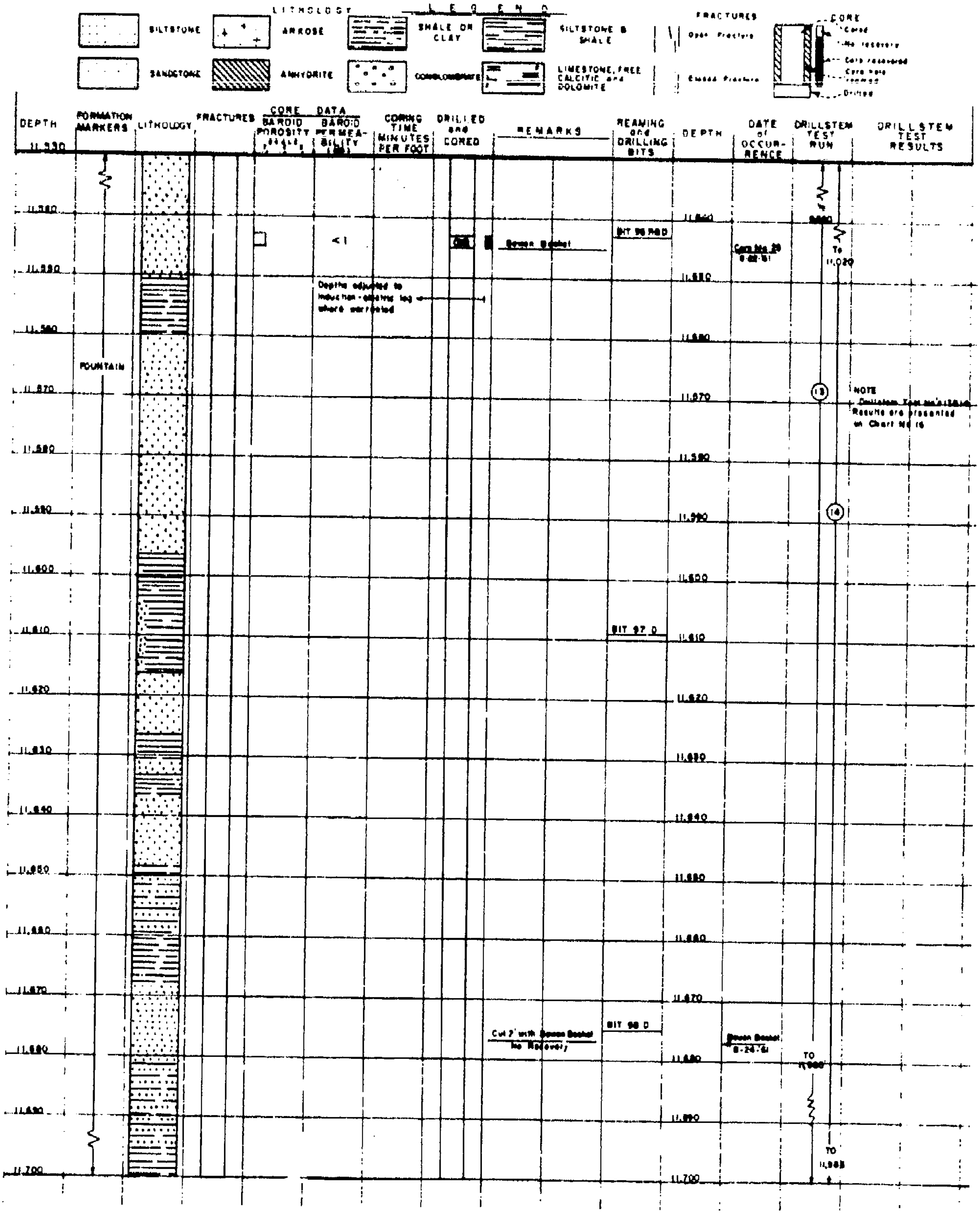
GRAPHICAL REPRESENTATION OF FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL PRESSURE INJECTION DISPOSAL WELL

FIGURE 10

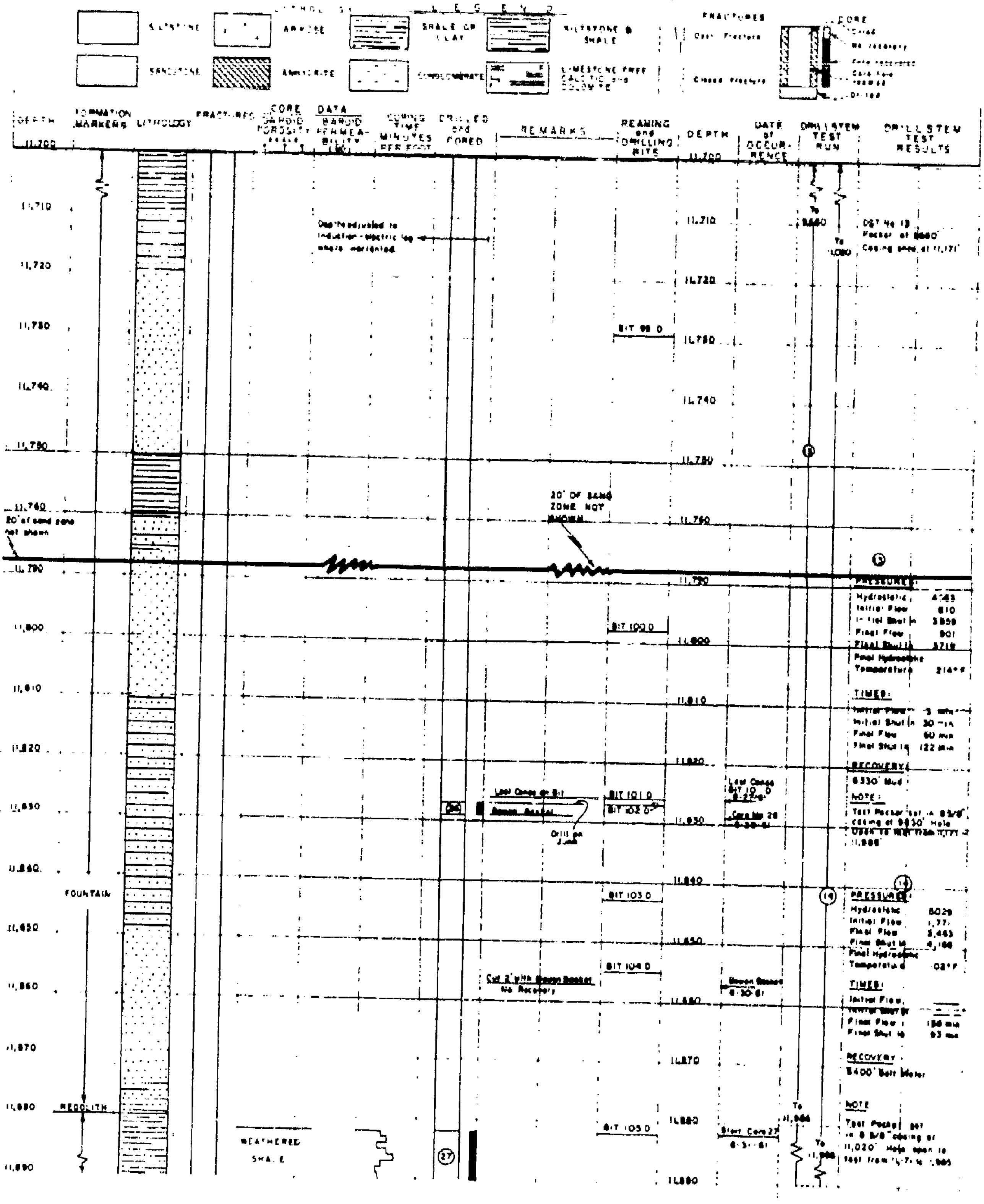
INTERVAL 11,530 - 11,700



GRAPHICAL REPRESENTATION OF
FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL

FIGURE 10.

INTERVAL 11,700 - 11,890

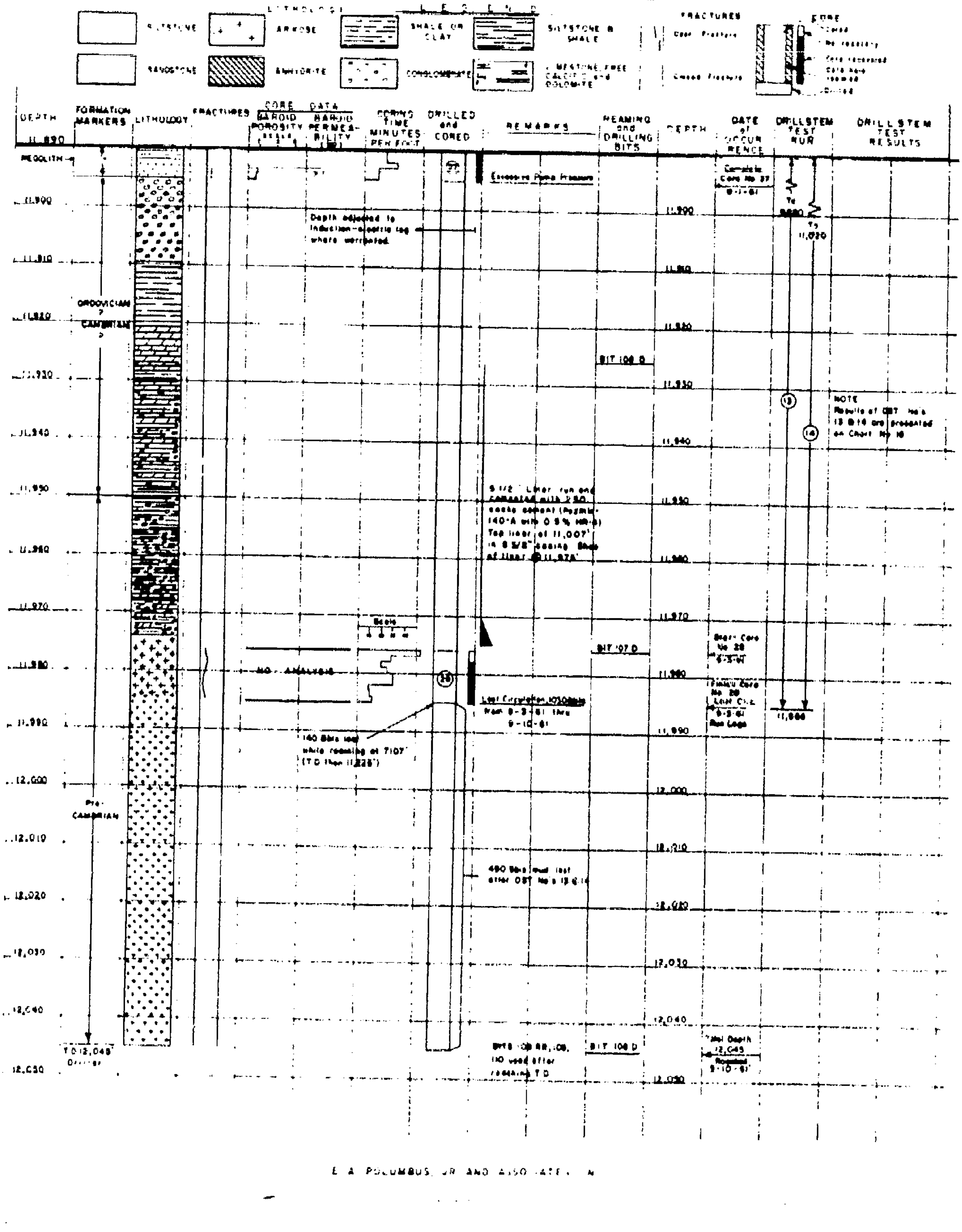


E. A. POLUMBUS, JR. AND ASSOCIATES, INC.

FIGURE 10.

NO. 17
INTERVAL 11,890 - 12,050

GRAPHICAL REPRESENTATION OF FORMATION EVALUATION DATA
ROCKY MOUNTAIN ARSENAL PRESSURE INJECTION DISPOSAL WELL



E. A. POLUMBUS, JR. AND ASSOCIATES, INC.

Figure 11

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL

CASING DETAILS

DIAGRAMATIC DRAWING

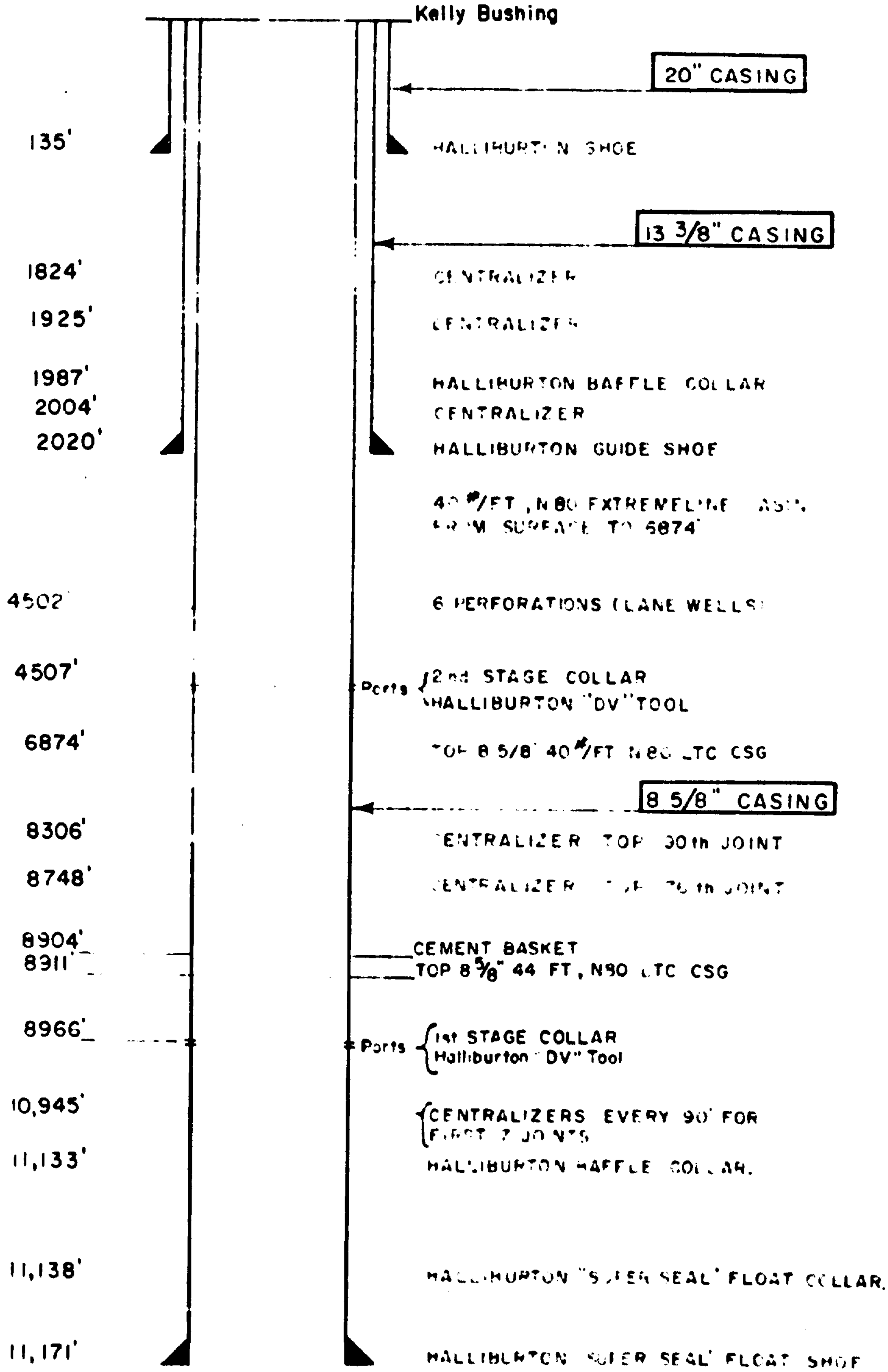
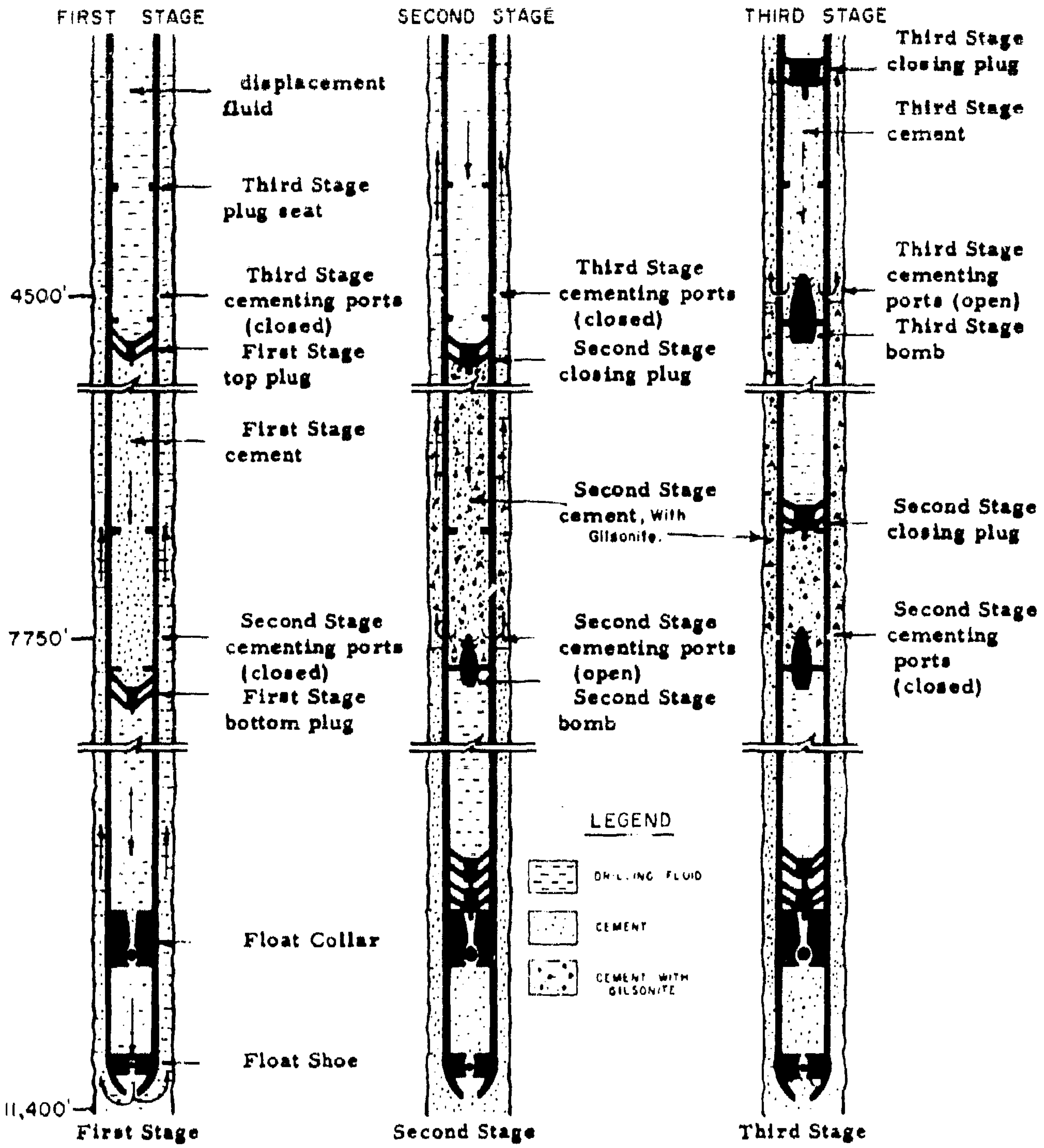


Figure 12

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL

Schematic Diagram of Typical Three-Stage Cementing Operation

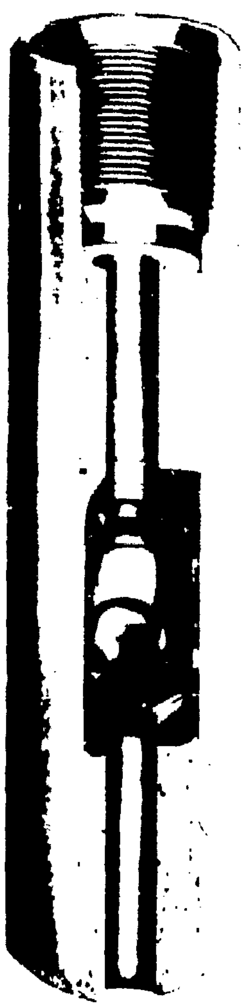


E. A. POLUMBUS JR. AND ASSOCIATES INC.

FIGURE 13

SPECIAL SUBSURFACE EQUIPMENT

TYPE LINER
FLOAT SHOE



MODEL "D"
PACKER

STRATIGRAPHIC SECTION
ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
SECTION 26, T2S - R67W
ADAMS COUNTY, COLORADO
ELEVATION KB 5,203'

		DEPTH	
		Below Kelly Bushing	Sea Level Datum
Tertiary, Tertiary-Cretaceous	Surface to	460'	
Cretaceous			
Laramie		460'	+4,743'
Fox Hills		1,250'	+3,953'
Pierre Shale		1,480'	+3,723'
Hygiene Zone		5,448'	- 245'
Niobrara		7,710'	-2,507'
Codell Sand		Absent	
Carlile Shale		8,078'	-2,875'
Greenhorn Limestone		8,120'	-2,917'
Graneros Shale		8,345'	-3,142'
"J" Sand		8,485'	-3,282'
"Dakota" Sand		8,633'	-3,430'
"Lakota" Sand		8,730'	-3,527'
Jurassic			
Morrison Formation		8,786'	-3,583'
Triassic			
Lykins Formation		8,972'	-3,769'
Permian			
Lyons Formation		9,582'	-4,379'
Pennsylvanian			
Fountain Formation		9,772'	-4,569'
Regolith		11,880'	-6,677'
Cambrian? Ordovician?		11,895'	-6,692'
Pre-Cambrian		11,950'	-6,747'
	TOTAL DEPTH	12,045'	-6,842'

CORE DESCRIPTIONS
ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
SECTION 26, T2S - R67W
ADAMS COUNTY, COLORADO

Core #1	("J" Sandstone) 8502-8529 Cut 27' Rec. 27'.
5'	Sandstone, very shaly, dark grey, fine grained. Carbonaceous streaks and material disseminated throughout, tight, oil odor, very weak fluorescence and cut
3 1/2'	Sandstone, fine, grey with streaks of buff, quartzitic, vertically fractured, streaks of oil stain, faint odor, fluorescence and cut.
1'	Shale, black, hard.
5 1/2'	Sandstone, fine, grey with streaks of buff, quartzitic, vertically fractured, streaks of oil stain, faint odor, fluorescence and cut.
2'	Sandstone, fine, light grey, quartzitic, no stain, no odor, no fluorescence.
1 1/2'	Shale, black, thin bedded, poker chips.
1 1/2'	Sandstone, fine, medium grey, quartzitic, no stain, no odor, no fluorescence.
1/4'	Sandstone, fine, dark grey, very shaly, with carbonaceous material disseminated throughout, oil odor, scattered stain, scattered fluorescence, and weak cut.
1/4'	Sandstone, fine, medium grey, quartzite, no stain, no odor, no fluorescence.
6 1/2'	Sandstone, fine, dark grey, very shaly, with carbonaceous material disseminated throughout, oil odor, scattered stain, very weak fluorescence.
Core #2	("J" Sandstone) 8531-8566 Cut 35', Rec. 35'.
35'	Reworked sandstone and shale.

Core #3	(Dakota-Lakota Group) 8637-8670' Cut and Rec. 34'.
12'	Sandstone, fine grained, grey. Quartzitic, slightly pyritic, with shale breaks 1/16" thick every [illegible] to 6". No show of hydrocarbon
7'	Shale, black.
1'	Shale, black, interbedded with sand, fine grained. Quartzitic, 1/16" to 1" thick.
1'	Shale, black, with sandstone pods.
3'	Shale, black, interbedded with sandstone, grey, quartzitic 1/16" to 1" thick.
1'	Shale, black.
2'	Shale, black with sandstone pod inclusions.
7'	Shale, black, fissle.
Core #4	(Dakota-Lakota Group) 8673-8685' Cored 12' Rec. 10'.
10'	Sandstone, fine, medium grey, quartzitic. No shows of hydrocarbon.
Core #5	(Dakota-Lakota Group) 8688-8694' Cut and Rec. 6'.
1/2'	Shale, black.
2'	Sandstone, fine grained, dark grey shale cement. Salt and pepper carbonaceous material disseminated throughout, quartzitic.
1/2'	Shale, black.
3'	Sandstone, fine grained, dark grey shale cement. Salt and pepper carbonaceous material disseminated throughout, quartzitic and pyritic.

Core #6 (Lyons Sandstone) 9597-9607 No recovery.

Core #7 (Lyons Sandstone) 9609-9632 Cut and Rec. 23'.

23' Sandstone, fine grained, orange to light red, very quartzitic, highly fractured, no shows.

Core #8 (Lyons Sandstone) 9656-9665 Cut 9' and Rec. 9'.

9'
9 Sandstone, fine grained, orange to dark red, Quartizitic, red shale laminae 1/64" or less thick. Separates 1/2" - 1 1/2", sandstone intervals throughout core. Fractures from 9665-9665 1/2, 9668-9669, 9670 1/2-9672.

Core #9 (Lyons Sandstone) 9669-9674 Cut 5', Rec. 5'.

5' Sandstone, fine grained, orange, quartzitic, one hairline fracture and one open fracture exhibited along face of the core.

Depth correction 9681 = 9674

Core #10 (Lyons Sandstone) 9676-9678 Cut 2', Rec. 1 1/2'.

1 1/2' Sandstone, fine grained, orange, quartzitic, one hairline fracture and one open fracture exhibited along face of the core.

Core #11 (Lyons Sandstone) 9681-9698 Cut 17', Rec. 16 1/2

16 1/2' Sandstone, fine grained, orange, quartzitic, red shale laminae 1/64" or less in thickness separating sandstone bedding from 1/2" to 1 1/2" thick. Open fracture in top 1 1/2'. Hairline fractures from 1/4" to 1" long throughout core.

Core #12 (Lyons Sandstone) 9698-9707 Cut and Rec. 9'.

9' Sandstone, fine grained, very silty, quartzitic, 1/2" red shale at 9699 3/4".

Bedding:	Horizontal bedding	9698-9698 1/2
	10° dip in bedding	9698 1/2-9707

Fractures:	9698	- 9699	Closed Fracture
	9699	- 9701	No Fracture
	9701	- 9701.5	Open Fracture
	9701.5	- 9702.5	No Fracture
	9702.5	- 9703.5	Closed Fracture
	9703.5	- 9703.75	No Fracture
	9703.75	- 9702	Open Fracture

Core #13 (Lyons Sandstone) 9707-9727 Cut and Rec. 20'.

20' Sandstone, fine grained, very silty, quartzitic, abundant maroon shale partings 9717.8-9718.2'. Dark maroon shale very silty 9726.5-9726.6. 9721.2-9727 interval of core contains ultra silty fine grained sandstone, quartzitic.

Bedding:	Horizontal bedding	9707 - 9718.1
	10° dip in bedding	9718.1 - 9722.5
	Horizontal bedding	9722.5 - 9727

Fractures:	9708 - 9708.5	Open Fracture
	9708.5 - 9710.2	No Fractures
	9710.2 - 9710.8	Open Fracture
	9710.8 - 9711	Closed Fracture
	9711 - 9711.5	2 Open Fractures
	9711.5 - 9712.5	Closed Fracture
	9712.5 - 9718.5	No Fractures
	9718.5 - 9719.5	Closed Fracture
	9719.5 - 9721.5	Open Fracture
	9721.5 - 9721.7	Closed Fracture
	9723.9 - 9724.1	Open Fracture
	9724.1 - 9724.5	No Fracture
	9724.5 - 9724.7	1 Open and 1 Closed Fracture
	9724.7 - 9725	No Fracture
	9725 - 9725.5	Open Fracture

Core #14 (Fountain Formation) 9892-9935 Cut 43' Rec. 35 1/2'

2 1/2'	Siltstone, red, shaly, quartzitic.
1 1/2'	Shale, maroon, with red siltstone laminae.
10'	Siltstone, red, quartzitic.
6'	Sandstone, red, fine grain, quartzitic.
1/2'	Shale maroon.
3'	Siltstone, red, quartzitic.
1'	Shale, maroon, silty.
9 1/2'	Siltstone, red, quartzitic
1 1/2'	Shale, maroon & siltstone bottom 3" gray dolomite.

Open & closed fractures throughout core, fracture surface contain microscopic calcite fill. 9915 contained 2 calcite inclusions 1/2" thick.

Core #15	(Fountain) 10, 121-10, 158 Cut 37' Rec. 36'.
6'	Siltstone grading to sandstone, fine grained, red, hard, quartzitic, trace of feldspar.
2'	Siltstone grading to sandstone, fine grained, red, hard, quartzitic, trace of feldspar with few calcite inclusions.
1'	Siltstone grading to sandstone, fine grained, red, hard, quartzitic, trace of feldspar with numerous calcite inclusions.
3'	Siltstone with trace fine grained sandstone, red, hard, quartzitic, abundant feldspar.
1/2'	Siltstone with trace fine grained sandstone, red, hard, quartzitic, abundant feldspar and few thin laminae of black carbonaceous material.
1 1/2'	Sandstone, fine grained, red, hard, abundant feldspar.
3'	Sandstone, fine grained with siltstone, red, hard, quartzitic, some feldspar.
3'	Sandstone, fine grained with siltstone, red, hard, quartzitic, abundant feldspar.
8'	Sandstone, fine grained with siltstone, red, hard, quartzitic, some feldspar, some calcite on fracture planes.
4'	Sandstone fine grained, red, hard, quartzitic, some feldspar.
4'	Sandstone fine grained, red, hard, quartzitic, abundant feldspar.

Vertical fracture observed in the following intervals: 10, 127-10, 132; 10, 137-10, 138; 10, 140-10, 156.

Bedding is horizontal except as follows:

10, 121 1/2-10, 123	10 °
10, 123 1/2-10, 124	10-15 °
10, 133 1/2-10, 135	20 °

Core #16	(Fountain) 10, 317-10, 321 Cut 4' Rec. 2'.
2'	Shale, maroon, micaceous.

Core #17	(Fountain) 10,388-10,401 Rec. 12'.
1'	Sandstone, greenish-white, fine grained. Highly calcareous, hard, somewhat friable when broken. Irregular bedding. Micaceous.
3'	Siltstone, maroon, micaceous with shale laminae. Slightly to moderately calcareous with highly calcareous greenish-white, fine grained sandstone inclusions 1/4 to 1/2" diameter. Flat bedded, hard.
5'	Sandstone, pink, fine grained, arkosic, moderately to slightly calcareous, hard. Contains coarse quartz and feldspar grains randomly scattered and quartz and feldspar pebbles near the base. Fractured vertically to near vertically. 94.3 to 95.7 interval contains eight thin (average 1/8" thick), irregular, greenish-white fine grained sandstone beds, highly calcareous.
1/2'.	1/2' shale bed, maroon, noncalcareous, dipping at 30 degrees, hard.
2 1/2'	Sandstone, pink, fine grained, arkosic, moderately to slightly calcareous, hard. Fractured vertically to near vertically.

Note: Sandstones contain much kaolinite cement.

Fractures:			
	10,391.5	-	10,392.0
	10,392.2	-	10,397.5
	10,398.0	-	10,400.0

Core #18	(Fountain) 10,594-10,644 Cut 50' Rec. 51'.
2.0'	Siltstone, very shaly with streaks of arkose, medium, pink, calcareous.
0.2'	Arkose, white, fine, very calcareous.
0.8'	Arkose, pink, very fine grading to siltsone, very shaly, with fine white sandstone inclusions, calcareous.
1.0'	Arkose, fine to medium, very shaly, dark red, 15° dips, calcareous.
4.0'	Shale grading to siltstone, dark red, very calcareous.
1.0'	Shale and siltstone as next above, noncalcareous with 1" streak of green white medium arkose, noncalcareous.
2.0'	Arkose, medium, angular, very shaly, very calcareous, dark red, with white medium gray arkose inclusions, very calcareous. Inclusions cut across bedding planes and they are 2"-5" thick.

Core #18
(Continued)

1.0'	Arkose, red and white, as next above with 3/4" thick bed of white.
3.0'	As next above. Arkose predominantly red with white inclusions in center portion of interval from 2"-4" thick. Upper portion has minute calcareous (white) inclusions.
3.0'	Arkose, medium, very shaly, calcareous, dark red.
1.0'	Arkose, medium, red, very shaly with 1/2-2" streaks of white arkose, medium, very calcareous.
1.0'	Shale, dark red, with streaks of white medium arkose, very calcareous.
6.0'	Siltstone very shaly, calcareous, dark red.
4.0'	Arkose fine to medium, very shaly and silty, dark red, very calcareous.
0.5'	Arkose, medium, white, very calcareous, dark red.
0.5'	Shale and siltstone, dark red, calcareous.
0.5'	Shale and siltstone, as next above with irregular inclusions of gray sandy limestone, dense.
1.0'	Siltstone and shale, dark red, very calcareous.
0.5'	Limestone, gray, dense.
7.0'	Shale, maroon, hard, calcareous.
0.5'	Shale, as above, with sandstone, dark gray fine inclusions, noncalcareous.
3.5'	Shale, maroon, noncalcareous, hard.
1.0'	Shale, dark red, calcareous and gray dense limestone mixed.
2.0'	Siltstone and shale, dark red, hard, calcareous.
0.5'	Arkose, very coarse, angular, very shaly, dark red.
1.5'	Siltstone and shale, micaceous, dark red to maroon with floating mica and quartz grains.
2.0'	Arkose, coarse, calcareous, angular, with streaks of siltstone, calcareous.

Core #19	(Fountain) 10,796-10,846 Cut 50' Rec. 48'.
6.0'	Shale, red, maroon, micaceous, calcareous.
.8'	Arkose, medium grained, very micaceous (biotite) slightly calcareous, greenish grey.
1.7'	Arkose as above with shale streaks, maroon, micaceous.
1.3'	Arkosic conglomerate with quartz and feldspar pebbles. Matrix pink. Pebbles pink, maroon, black, very shaly.
1.2'	Shale, red, soft.
7.0'	Arkose, medium grained, much biotite mica, kaolinite cement. Two maroon shale partings 2"-4" at 10,809.8 and 10,811.8, whitish pink, slightly calcareous. Streaks very coarse grained to conglomeritic. Dip 15° cross bedded.
4.0'	Maroon shale, micaceous interbedded with pinkish white arkose, coarse grained, minute streaks green shale. Slightly calcareous.
3.5'	Maroon shale, micaceous, streaks green shale and arkose, coarse grained, pinkish white.
2.5'	Arkose, coarse grained, biotite mica, streaks shale, maroon. (Arkose greenish white).
1.5'	Shale, maroon, micaceous.
.5'	Arkose, medium to coarse grained, abundant biotite mica, greenish white. Streaks maroon shale.
1.0'	Shale, maroon, micaceous.
1.5'	Arkose, coarse grained, muscovite and biotite mica, kaolinite cement, maroon and green shale cement.
2.0'	Arkosic conglomerate, green shale and kaolinite cement, streaks maroon shale.
2.0'	Arkosic conglomerate as above with much maroon shale.
1.5'	Arkose very coarse grained, greenish white. Much kaolinite and green shale cement. 0-15° dip.
2.0'	Arkose as above, many laminae maroon shale.
1.0'	Shale, maroon, micaceous, streaks arkose as above.
1.2'	Arkose, coarse grained, greenish white, kaolinite cement. 15° dip.
1.0'	Shale, maroon, with reddish brown limestone inclusions.

Core #19
(Continued)

.7'	Arkose, very fine to very coarse grained, greenish white kaolinite cement. Maroon and green shale laminae, inclusions brownish red limestone.
1.5'	Shale, maroon, very calcareous. Inclusions reddish brown, dense limestone.
1.0'	Shale, red, reddish brown limestone inclusions.

Fractures - Closed: 10,802.5 - 10,803.5
10,804.5 - 10,805.0
10,807.0 - 10,812.0
10,823.5 - 10,824.0
10,834.0 - 10,836.0
10,838.0 - 10,839.0
10,839.5 - 10,840.0

Core #20 (Fountain) 11,044-11,080 Cut 36' Rec. 34'.

3.5'	Shale, red, with reddish brown limestone inclusions.
.5'	Limestone, gray, dense.
1.0'	Shale, red, with reddish brown limestone.
6.5'	Shale, red, soft.
1.5'	Arkose, coarse, pinkish red, hard and tight, fractured.
2.0'	Shale, red, with reddish brown limestone inclusions.
2.5'	Shale, red, soft.
2.0'	Shale, dark red, silty.
4.0'	Arkose, pinkish white, coarse grained, kaolinite cement.
1.5'	Shale, maroon.
9.0'	Shale, red, soft.

Open Fractures 11,056-57
Close Fractures 11,065-66

Core #21	(Fountain) 11,129-11,178 Cut 49' Rec. 48'.
.5	Shale, dark red-purple, soft noncalcareous.
6.7	Arkose, medium to very coarse, angular, light maroon, containing muscovite and biotite mica, with pebbles of quartz 1/2" in diameter. Very shaly with maroon shale, noncalcareous.
2.0	Arkose as next above interbedded with maroon shale, noncalcareous.
4.6	Arkose as described above, noncalcareous.
.2	Shale, dark red.
5.0	Arkose, medium to very coarse, angular, light greenish white, containing muscovite and biotite mica. 20% kaolinite cement and muscovite, light green shale cement. Many streaks of chlorite.
3.5	Shale, dark red, soft.
2.0	Arkose, as described next above.
.5	Arkose, as described next above interbedded with red shale.
7.0	Shale, red, soft.
2.0	Shale, red, silty, micaceous.
4.0	Arkose, fine to very coarse, angular with pebbles of quartz 1/4" in diameter, very shaly, with green shale cement. Bottom foot slightly calcareous.
1.0	Shale, dark red, soft.
3.5	Shale, dark red, silty.
1.5	Arkose, fine, green-gray, very shaly containing biotite mica.
2.2	Arkose, as next above, interbedded with red shale.
1.3	Shale, red.
.3	Arkose, as next above, hard and tight.
1.2	Shale, red.
	Closed Fractures: 11,139 - 11,139.5 11,147 - 11,148.0 11,152 - 11,153.0 11,165 - 11,166.0

Core #22 (Fountain) 11,262-11,326 Cut 64' Rec. 40'.

0.5	Shale, red.
2.0	Arkose, Coarse, olive green, noncalcareous.
5.5	Arkose, very coarse to conglomeritic, maroon, very shaly with pebbles of quartz, clear to milky, and orthoclase feldspar.
2.0	Arkose, conglomerate, pink, primarily angular clear quartz and orthoclase feldspar.
1.0	Shale and arkose as next above interbedded.
2.0	Arkose, conglomerate, pink, primarily angular clear quartz and orthoclase feldspar.
1.5	Shale and arkose as next above interbedded.
6.0	Arkose, very coarse, maroon, angular, very shaly.
2.5	Arkose, conglomerate, pink, primarily angular clear quartz and orthoclase feldspar with 0.3' of maroon shale 1' from base.
2.5	Shale, maroon.
2.5	Arkose, very coarse, pink, primarily angular clear quartz and orthoclase feldspar.
2.0	Arkose, maroon, coarse to very coarse, very shaly, angular.
0.5	Shale, red plastic.
1.5	Arkose, coarse, maroon, very shaly, with pebbles of quartz, clear to milky, and orthoclase feldspar.
1.0	Arkose, very coarse, pink to green, predominantly angular, clear quartz and orthoclase feldspar.
3.0	Shale, maroon, micaceous.
2.0	Arkose, coarse, maroon, very shaly, with pebbles of quartz, clear to milky, and orthoclase feldspar
1.0	Arkose, coarse, maroon, very shaly.
1.0	Arkose, coarse, maroon, very shaly with pebbles of quartz.

Core #23 (Fountain) 11,364-11,394 Cut 30' Rec. 26'.

2.0	Arkose, white, coarse, predominantly clear quartz, orthoclase feldspar, muscovite mica, angular, white clay cement.
3.0	Arkose, maroon, coarse, with scattered pebbles of clear quartz, very shaly.
2.0	Arkose, white, coarse to conglomeritic, clear quartz and orthoclase feldspar, white clay cement, angular.
1.5	Shale, maroon, micaceous.
1.0	Arkose, medium, abundant biotite mica, whitish grey interbedded with maroon shale.
3.0	Arkose, very coarse to coarse, whitish pink. Clear quartz, orthoclase feldspar and muscovite and biotite mica, white clay cement, angular.
1.5	Shale, maroon, micaceous.
11.5	Arkose, coarse, maroon, with pebbles of quartz and orthoclase feldspar, muscovite and biotite mica, angular, very shaly.
.5	Shale, maroon, very micaceous.

Fractures: 11,367-11,368
11,369-11,370

Core #24 (Fountain) 11,447-11,475 Cut 28' Rec. 23'.

2.5	Shale, maroon.
4.5	Arkose, medium to coarse, white grading to maroon. Clean to very shaly.
2.0	Shale, maroon.
10.5	Arkose, coarse to conglomeritic, greenish white to pink.
1.5	Shale, maroon.

Fractures 11,453-11,454

Core #25	(Founatin) 11,543-11,545 Cut 2', Rec. 2'. (Bowen junk basket)
.3	Arkose, coarse, white, with pebbles of quartz and feldspar, fractured.
1.7	Shale, maroon, slickensides.
Core #26	(Fountain) 11,827-11,829 Cut 2', Rec. 2'. (Bowen junk basket)
1.0	Arkose, coarse, maroon, very shaly, fractured.
1.0	Shale, maroon.
Core #27	(Regolith) Corrected from 11,872-11,895 (driller's depth) to 11,882-11,895 (E-log depth) Cut and recovered 13'.
2.0	Shale, maroon.
3.5	Shale, purple-maroon, weathered, bottom foot very leached.
2.5	Shale, maroon, silty, weathered.
1.0	Shale, very hard, silty, maroon, with white leached irregular areas.
2.0	Shale, dark brownish red, soft.
2.0	Quartzite, reddish brown, with whitish green leached areas, fractured.
Core #28	Pre-Cambrian 11,976-11,985 Cut 9', Rec. 6.7'.
6.0	Biotite, hornblende, granite gneiss, fractured.
.7	Biotite, hornblende, granite gneiss and pegmatite.

Table 3

RIG DESCRIPTION

Company ______ Loffland Brothers ______ Rig No. ___ 7 ___

Drawworks: Make ___ Ideco ___ Model ___ PR 1050 ___

Compound: Make ___ National ___ Model ___ 3 Engine ___ No. Chains ______

Rotary Table: Type of Drive ___ Drawworks ___

Compound Engines: No. ___ 3 ___ Make ___ Caterpillar ___ Model ___ D-397 ___
Continuous HP Rating ___ 1350 ___ Oper. Speed at Cont. HP ___ 1150 RPM ___

Pump Engines: No. ___ Compounded ___ Make ______ Model ______
Continuous HP Rating ______ Oper. Speed at Cont. HP ______

Mud Pump: (1) Make ___ Emsco ___ Type ___ D-700 ___ Input HP ___ 700 ___
(2) Make ___ Emsco ___ Type ___ D-500 ___ Input HP ___ 500 ___

Derrick: Make ___ L. C. Moore ___ HT ___ 142' ___ Rated Load ___ 900,000 ___

Kelly: OD ___ 4 1/4" ___ ID ___ 2 1/2" ___ Length ___ 40' ___

Swivel: Make ___ National ___ Type ___ R-3 ___ ID ___ 2 3/4" ___

Hose: OD ______ ID ___ 3" ___ Length ___ 55' ___

Standpipe: OD ___ 4 1/2" ___ ID ___ 3 3/4" ___ Length ___ 50' ___

Drill Pipe: OD ___ 4 1/2" ___ ID ___ 3 3/4" ___ Grade ___ E ___ Weight ___ 16.60 ___

Tool Joints: Size ______ Type ___ XH ___ ID ______

Drill Collars: OD ___ 8" - 7" ___ ID ___ 3"/ 2 3/4" ___

Desander: Make ___ San Angelo ___ No. Cones ___ 3 ___ Power ___ Wak 135 GKU ___

Couplings: Make ______ Type ______ Size ______ Location ______

Torque Convertors: Make ______ Type ______ Size ______ Location ______

Operating Conditions:
Rotary Table Speed: 1st Gear ___ 30 ___ 2nd Gear ___ 50 ___ 3rd Gear ___ 65 ___
4th Gear ___ 80 ___ 5th Gear ___ 125 ___

Engine Idle: Vacuum ______ Speed ___ 400 RPM ___

Full Load Conditions:
Engine Speed ___ 1150 ___ rpm Vacuum ______ or Stack Temp. ___ 900 ___
Liner Size ______ Pressure ______ Pump Speed ______
Mud Weight ______ Rotary Speed ______ Depth ______

Table 4

SUMMARY - DRILLING AND CORING PERFORMANCE
ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL

	Footage		Net Drilling Days		Penetration Feet/Net Day (1)		Cores		Penetration Ratio
	Drilled	Cored	Drilling	Coring	Drilling (2)	Coring	No. Cut	Ft./Core	Drilling/Coring
Surface-"J" 0-8,485'	8,485'	-	14.0	-	606. (530)	-	-	-	
Top "J"-Lyons 8,485-9,582'	983'	114'	11.0	8.0	89.4 (46)	14.3	5	22.8'	6.2
Lyons-Fountain 9,582-9,772'	95'	95'	3.4	12.1	27.9 (15)	7.8	8	12.0'	3.6
Fountain-Regolith 9,772-11,880'	1,700'	408'	24.8	19.4	68.4 (39' RB) (51 insert)	21.0	13	31.4'	3.3
Regolith-Total Depth 11,880-12,045'	143'	22'	2.1	1.0	71.5 (49)	(3) 22.0#	2	11.0	4.4
Total	11,406'	639'	55.3	40.50	206.2	15.8	28	22.8	

(1) Includes coring time plus time reaming core hole.
(2) Figures in parenthesis in drilling penetration column denote feet per bit of drilled hole.
(3) Core hole not reamed.

Table 5

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
HOLE DEVIATION

Deviation	Depth	Deviation	Depth
3/4°	185'	1 1/2°	7,930'
0°	246'	1°	8,150'
1 1/2°	380'	1°	8,480'
1/2°	500'	1/4°	8,670'
1/2°	660'	1/2°	8,750'
3/4°	820'	1/4°	8,925'
3/4°	967'	1/2°	9,030'
3/4°	1,300'	3/4°	9,340'
1/2°	1,480'	1 1/4°	9,470'
1/4°	1,756'	3/4°	9,675'
1/4°	2,000'	3/4°	10,010'
0°	2,205'	1 3/4°	10,150'
1/2°	2,629'	2 1/4°	10,200'
1/4°	3,100'	2 1/2°	10,330'
1°	3,590'	3 3/4°	10,649'
1 1/2°	3,720'	4 3/4°	11,030'
1°	4,000'	6°	11,170'
1 1/4°	4,380'	6°	11,340'
1°	5,255'	5°	11,530'
1°	5,470'	7°	11,600'
1°	5,890'	5°	11,675'
3/4°	6,400'	5°	11,720'
1°	6,690'	5°	11,790'
2 1/2°	7,000'	5 1/2°	11,835'
3°	7,100'		
3 1/4°	7,211'		
3 1/4°	7,340'		

(Taken from Loffland Brothers daily drilling report.)

Page 1 of 3

BAROID DIVISION
NATIONAL LEAD COMPANY
DRILLING MUD RECORD

W.E. Gorhom, Jr. 9-6-61

COMPANY U S Government-Army Engr STATE Colorado
WELL Pressure Injection Disposal COUNTY Adams
CONTRACTOR Loffland Bros. LOCATION Rocky Mtn. Arsenal
ENGINEER Fred M. Lang 26 TWP 2S RNG 67W

CASING PROGRAM 20 inch at 125 ft
13⅜ inch at 2000 ft
8⅝ inch at 11,200 ft
TOTAL DEPTH 12,045 ft

DATE												PV	YP	Temp Deg F		Ca	SO_4	REMARKS AND TREATMENT
3-10-61	135'	9.0	54	26	0	10	4.4	1	3	10.5	300							
3-12	569	8.9	38	—	0	0	12.0	1	1	10.0	500				—	2	6	Mudded up w/Aquagel & water
3-13	820	9.2	40	16	0	3	7.6	2	1	9.5	700				—	6	20	Aquagel, Driscose, Tannex, Caustic
3-14	1,480														—			Drlg 20" hole
3-24	2,913	9.0	34	—	0	1	6.8	F.lm	¼	8.5	400	7	1		—			Logging & set 2,000' 13⅜" casing
3-26	4,134	9.5	32		0	0	7.4	1	N.l	9.0	500	6	0		—	2	6	Converted to low solids Condet mud
3-27	5,100	9.4	32		0	0	7.2	1	N.l	8.5	500	4	2		—			Drlg. 11" hole
3-30	6,435	9.4	31		0	0	8.4	1	"	9.0	500	5	0		—	1	6	6¾ pump liners - Ann. velocity 120'/min
4-3	7,695	9.4	38		1	7	8.8	2	"	8.0	500	10	1		—	1	6	
4-5	8,011	9.6	35		1	4	9.6	2	¼	8.0	500	8	0			PPM		-Converted to Gyp-QBroxin mud
4-6 (?)	8,482	9.7	40		2	10	7.8	2	1	8.5	11,000	11	3		7	1400		Added 1% Diesel O.l
4-9	8,519	9.6	48		4	16	6.4	2	¼	8.0	17,000	14	7		4	1400		Added Salt to inhibit filtrate
4-11	8,553	9.6	74		8	38	6.6	2	½	7.2	25,400	19	14		5	880		
4-14	8,658	9.8	60		4	28	6.0	2	1	7.6	10,400	18	12		4	960		Vis increased for coring & testing
4-15	8,662	9.7	74		5	32	4.8	1	½	8.5	11,500	24	14			880		Coring & testing
4-17	8,753	9.8	74		6	36	6.0	2	¾	8.5	19,300	22	18		4	880		Increasing Vis w/ Aquagel & Zeogel
4-20	8,871	9.7	63		3	28	4.5	2	1	8.0	11,000	21	18	132	5	960		
4-23	8,978	9.9	61		1	18	5.4	2	1½	8.5	11,000	19	12		6	960		Flowline temp. of mud 132°F
5-1	9,410	10.1	56		1	25	8.6	2	½	8.5	8,745	17	11		6	1,200		Fishing - twisted off
5-2	9,567	10.0	57		2	26	6.0	2	¼	9.0	12,375	20	12		3	1080		
5-3	9,592	10.0	80		4	28	6.0	2	½	9.0	13,860	25	20	144	7	1240		
5-5	9,616	9.9	61		1	25	6.2	2	¼	8.0	11,000	17	11			1200		Solid content 16%
5-7	9,616	9.6	62		2	18	5.2	2	¼	9.0	7,425	21	16	130				Reaming
5-9	9,663	9.8	75		4	28	5.6	2	¼	7.2	7,400	25	17			1020		
5-12	9,681	9.8	90		3	25	7.0	2	½	8.5	6,930	24	17		6	1160		Coring & reaming
5-14	9,683	9.5	95		3	25	6.6	2	½	8.0	3,400	23	14		4	1320		Losing mud
5-16	9,698	9.6	69		1	18	7.2	2	½	9.0	4,950	22	15			2000		
5-19	9,726	9.7	92	34	2	22	7.4	2	½	9.0	3,800	25	19		3	1040		Coring & reaming
5-22	—	9.9	90		1	21	7.4	2	¼	9.0	4950	28	19		3	1000		3% lost circulation material in mud
5-23	9,749	9.6	54		0	10	9.2	2	¼	8.0	4950	19	9		7	1080		Lost 100 bbls. mud
5-24		9.4	56		1	10	9.6	2	½	8.5	2800	23	6		7	"		Lost complete returns
5-25	9,892	9.5	73		1	18	8.0	2	1½	9.0	3300	26	10			1000		LCM content 4%
5-29	9,935	9.4	78		3	30	6.4	2	1½	9.0	3300	27	12		3	900		LCM content 5%
5-31	9,957	9.2	94		3	40	8.0	2	1½	9.0	2475	24	14		1	920		
6-1	9,966	9.4	67		1	20	8.0	2	1½	9.0	2475	22	9		2	880		9% Solids - 4% LCM - lost 200 bbls.
6-2	10,016	9.2	110		5	35	9.2	2	1¼	7.6	1650	20	20		2	1000		LCM-3% lost 100 bbls
6-5		9.5	60		1	16	7.0	2	1½	9.0	1650	23	7		1	1000		LCM - 8% to 10%
6-6	10,057	9.5	71		3	24	7.2	2	1½	8.5	1650	30	10			1000		Lost 300 bbls. mud LCM - 8%

MUD MATERIAL USED

MATERIAL	UNIT	AMOUNT	COST $
Aquagel			
Zeogel			
Baroid			
Impermex			
Imp Pres			
Barafos			
Other Phos			
Tannex			
Carbonox			
Fibertex			
Jelflake			
Pana Seal			
Lime			
Caustic Soda			
Soda Ash			
Gypsum			
Salt			
Defoamer			
Oil			
Sales Tax			

Mud materials included on separate report.

Legend:
PV = Plastic Viscosity
YP = Yield Point
LCM = Lost circulation material
Ca = Calcium
SO_4 = Sulphate

TOTAL COST $ 96,113.87

TABLE 6
Pg 1

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BAROID DIVISION
NATIONAL LEAD COMPANY
DRILLING MUD RECORD

W.E. Gorham, Jr. 9-6-61

COMPANY U.S Government-Army Engr. STATE Colorado
WELL Pressure Injection Disposal COUNTY Adams
CONTRACTOR Loffland Bros. LOCATION Rocky Mtn. Arsenal
ENGINEER Fred M. Lang SEC 26 TWP 2S RNG 67 W

CASING PROGRAM 20 inch at 125 ft
13 3/8 inch at 2,000 ft
8 5/8 inch at 11,200 ft
TOTAL DEPTH 12,045 ft

DATE	DEPTH	WEIGHT	VISCOSITY		GELS		FILTRATE		SAND	pH		PV	YP	Ca SO4	REMARKS AND TREATMENT
6-8-61	10,100	9.4	87		8	38	6.4	2	½	9.5	1320	30	15	1280	LCM content - 12%
6-11	—	9.1	72		1	11	7.0	2	½	9.0	1300	26	12	1760	LCM content - 20%
6-13	—	9.2	68		2	15	8.4	2	½	9.0	1650	24	12	1520	Lost 50 bbls mud - LCM 12%-15%
6-14	10,243	9.3	90		3	24	7.4	2	½	9.0	1350	21	21	1400	LCM - 12%
6-16	10,331	9.3	81		2	12	8.0	2	½	8.5	1300	26	12	1000	LCM content 10%-13%
6-19	10,392	9.3	88		3	28	8.2	2	½	8.0	700	30	15	880	
6-21	10,441	9.5	74	36	2	24	7.4	2	1	9.0	800	29	14	1140	LCM content 12%
6-24	—	9.5	80		2	24	7.2	2		9.0	700	30	14	1100	
6-25		9.2	90		2	10	8.0	2	½	9.0	700	23	14	800	Losing circulation - (Pit check)
6-27	10,589	9.2	78		2	10	6.4	2		9.5	700	22	17	900	LCM content 30% - Drlg.
6-29	10,644	9.4	81		2	28	8.0	2		8.0	600	22	18	1000	Lost 75 bbls. mud 6/28 and 730 bbls on 6/30
7-1	10,652	9.3	73		2	25	8.8	2		7.6	600	20	15	1000	LCM - 20% - 30%
7-2	—	9.4	109		3	35	9.8	2		9.0	600	28	17	1120	Added Impermex & Preservative
7-4		9.5	84		2	21	8.8	2		9.0	600	27	14	1120	LCM content 15%-18%
7-6	10,878	9.4	120		4	30	6.8	2		8.5	600	32	19	1400	Reaming
7-9	10,987	9.4	76		2	20	7.4	2		8.0	1000	24	15	1400	
7-11	11,090	9.2	73		3	25	8.4	2	½	9.5	1000	19	11	1000	LCM - 30% lost 770 bbls. mud
7-12	—	9.4	90		4	25	6.0	2		9.0	1000	25	20	1240	Losing mud - LCM 35% - 37%
7-14	—	9.4	87		3	21	7.6	2		8.5	1000			1580	Losing circulation
7-17		9.3	74		5	30	9.6	2		7.2	1000				LCM content 10%-12%
7-19	—	9.3	90		5	30	5.0	2	½	8.5	1000	27	16	1420	
7-20		9.4	101		5	46	4.4	2		9.5	1000			2000	
7-21	—	9.4	142		14	45	5.6	2		9.0	900	26	31	2000	LCM - 10%
7-22	11,225	9.4	152		11	40	4.6	2		9.0	900	35	25		
7-23	11,225	9.4	110		10	45	3.2	2		9.0	900	26	24	5000	Reaming out key seat
7-24	11,225	9.4	85		4	20	5.0	2		9.0	1000	30	15	4000	"
7-25	11,225	9.3	135		10	40	4.4	2		8.5	900	30	28	4400	LCM - 8%
7-27	11,225	9.2	99		6	36	3.6	2		9.0	800	32	16	4000	Reaming key seat
7-28	11,225	9.1	117		10	21	3.6	2		8.5	800	26	29	15 3600	Added 15% oil - reaming key seat
7-29	"	9.1	86		3	24	4.8	2		8.5	800	26	14	13 3800	Circulating to log
7-30	"	9.3	111		4	28	4.8	2		9.5	900	34	14	3800	Circulating to log 7/30 & 7/31
8-1	11,225	9.2	115		2	20	5.8	2		9.0	800	36	20	14 4000	Circulating to run casing at 11,200'
8-3	11,225	9.0	86		4	28	6.8	2		8.5	900	24	14	10 3600	
8-5	11,200														
8-12	11,225	8.5	37		0	1	8.4	1		9.5	400	10	3		Drilled cement & mud up w/ Aquagel
8-16	11,352	8.8	36		0	1	6.8	1	¼	10.0	500	11	3		Aquagel - Chemical mud
8-19	11,460	8.8	44		0	3	6.2	1		9.5	400	18	7		Coring
8-22	11,568	8.9	45		1	4	8.0	1	¼	9.5	400	20	12		Coring
															Drilling 6¼" hole.

MUD MATERIALS USED (Total)

MATERIAL	UNIT	AMOUNT	COST $
Aquagel			
Baroco			
Zeogel			
Baroid			
Impermex			
Imp Pres			
Driscose			
Baratis			
Other Pros			
Quebracho			
Tannex			
[illegible]			
Carbonox			
Hydrotan			
Hydrocarb			
Lignox			
Anhydrox			
Smentox			
Fibertex			
Micatex (F)			
Micatex (R)			
Jelflake			
Puna Seal			
Tuf Plug			
Lime			
Caustic Soda			
Soda Ash			
Gypsum			
Salt			
Defoamer			
Oil			
Drayage			
Sales Tax			

TOTAL COST $

TABLE 6
Pg. 2

TABLE 6

Pg. 3

BAROID DIVISION
NATIONAL LEAD COMPANY
DRILLING MUD RECORD

Page 3 of 3

W. E. Gorham, Jr. Date 9-6-61

COMPANY U.S Government-Army Engr. STATE Colorado
WELL Pressure Injection Disposal COUNTY Adams
CONTRACTOR Loffland Bros. LOCATION Rocky Mtn. Arsenal
ENGINEER Fred M. Lang SEC 26 TWP 2-S RNG 67-W

CASING PROGRAM 20 inch at 125 ft
13 3/8 inch at 2,000 ft
8 5/8 inch at 11,200 ft
TOTAL DEPTH 12,045 ft

DATE	DEPTH ft	WEIGHT	VISCOSITY		GELS		FILTRATE		SAND	pH		PV	YP
8-24	11,792	9.0	48	25	0	3	7.0	1	½	9.0	400	22	7
8-27	11,827	8.9	45		1	4	6.0	2		7.6	400	20	5
8-30	11,872	9.0	41		0	3	7.4	2	½	9.0	400	17	1
9-2	11,885	9.1	41		1	4	6.0	1	½	9.5	500	17	3

REMARKS AND TREATMENT

MUD MATERIALS USED (Total)

MATERIAL	UNIT	AMOUNT	COST $
Aquagel			
Baroco			
Zeogel			
Baroid			
Impermex			
Imp Pres.			
Driscose			
Boratus			
Other Phos			
Quebracho			
Tannex			
[illegible]			
Carbonox			
Hydrotan			
Hydrocarb			
Lignox			
Anhydrox			
Smentox			
Fibertex			
Micatex (F)			
Micatex (K)			
Jelflake			
Plug-Seal			
Tuf Plug			
Lime			
Caustic Soda			
Soda Ash			
Gypsum			
Salt			
Defoamer			
Oil			
Drayage			
Sales Tax			

TOTAL COST $

Distributor

Table 7

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
SUMMARY OF CORES

Formation or Member	Core No.	Driller's Depths	Depths Adjusted to Electric Log	Feet Cut	Unit Total	Feet Rec.	Unit Total
"J" Sandstone	1	8,492- 8,519	8,502- 8,529	27		27	
	2	8,521- 8,556	8,531- 8,566	35		35	
					62		62
Dakota Sandstone	3	8,623- 8,657	8,636- 8,670	34		34	
	4	8,660- 8,672	8,673- 8,685	12		10	
	5	8,675- 8,681	8,688- 8,694	6		6	
					52		50
Lyons	6	9,604- 9,614	9,597- 9,607	10		0	
	7	9,616- 9,639	9,609- 9,632	23		23	
	8	9,656- 9,665	9,656- 9,665	9		9	
	9	9,669- 9,674	9,669- 9,674	5		5	
	10	9,676- 9,678	9,676- 9,678	2		1.5	
	11	9,681- 9,698	9,681- 9,698	17		16.5	
	12	9,698- 9,707	9,698- 9,707	9		9	
	13	9,707- 9,727	9,707- 9,727	20		20	
					95		84
Fountain	14	9,892- 9,935	9,892- 9,935	43		35.5	
	15	10,121-10,158	10,121-10,158	37		36	
	16	10,317-10,321	10,317-10,321	4		2	
	17	10,388-10,401	10,388-10,401	13		12	
	18	10,594-10,644	10,594-10,644	50		51	
	19	10,796-10,846	10,796-10,846	50		48	
	20	11,044-11,080	11,044-11,080	36		34	
	21	11,129-11,178	11,129-11,178	49		48	
	22	11,262-11,326	11,262-11,326	64		40	
	23	11,364-11,394	11,364-11,394	30		26	
	24	11,447-11,475	11,447-11,475	28*		23 *	
	25	11,543-11,545	11,543-11,545	2		2	
	26	11,827-11,829	11,827-11,829	2		2	
					408		359.5
Regolith	27	11,872-11,885	11,882-11,895	13		13	
					13		13
Pre-Cambrian	28	11,976-11,985	11,976-11,985	9		6.7	
					9		6.7
TOTALS				639		575.2	

* Includes 2 feet cut with Bowen junk basket below 26-foot interval cut with conventional diamond core.

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
CORING EQUIPMENT SUMMARY

Corehead (Serial No.)	Type	Core No.	Size O.D.	Size I.D.	Feet Cut	Total Cut By Bit	Core Barrel O.D.	Core Barrel Length	Kelly Extension	Jars (Size)
C-18404	Diamond	1	8 7/8"	4 3/8"	27		6 5/8"	50'	-	6 3/4"
C-18404	"	2	8 7/8"	4 3/8"	35		6 5/8"	50'	-	6 3/4"
C-18404	"	3	8 7/8"	4 3/8"	34	96'	6 5/8"	50'	-	6 3/4"
C-18350	"	4	8 9/16"	4 3/8"	12		6 5/8"	50'	30'	6 3/4"
C-18350	"	5	8 9/16"	4 3/8"	6	18'	6 5/8"	50'	30'	6 3/4"
R-18182	"	6	8 7/8"	4 3/8"	10		6 5/8"	50'	30'	6 3/4"
R-18182	"	7	8 7/8"	4 3/8"	23		6 5/8"	50'	30'	6 3/4"
R-18182	"	8	8 7/8"	4 3/8"	9		6 5/8"	50'	-	6 3/4"
R-18182	"	9	8 7/8"	4 3/8"	5		6 5/8"	50'	-	6 3/4"
R-18182	"	10	8 7/8"	4 3/8"	2		6 5/8"	50'	30'	6 3/4"
R-18182	"	11	8 7/8"	4 3/8"	17	66'	6 5/8"	50'	30'	6 3/4"
R-18007	"	12	8 7/8"	4 3/8"	9		6 5/8"	50'	30'	6 3/4"
R-18007	"	13	8 7/8"	4 3/8"	20	29'	6 5/8"	50'	30'	6 3/4"
R-18674	"	14	7 13/16"	4 3/8"	43		6 5/8"	50'	30'	6 3/4"
R-18674	"	15	7 13/16"	4 3/8"	37		6 5/8"	50'	30'	6 3/4"
R-18674	"	16	7 13/16"	4 3/8"	4		6 5/8"	50'	30'	6 3/4"
R-19674	"	17	7 13/16"	4 3/8"	13		6 5/8"	50'	30'	6 3/4"
R-18674	"	18	7 13/16"	4 3/8"	50		6 5/8"	50'	30'	6 3/4"
R-18674	"	19	7 13/16"	4 3/8"	50	197'	6 5/8"	50'	30'	6 3/4"

Table 8 Pg. 2

Corehead (Serial No.)	Type	Core No.	Size O.D.	Size I.D.	Feet Cut	Total Cut By Bit	Core Barrel O.D.	Core Barrel Length	Kelly Extension	Jars (Size)
R-18675	Diamond	20	7 13/16"	4 3/8"	36'		6 5/8"	50'	30'	6 3/4"
R-18675	"	21	7 13/16"	4 3/8"	49'		6 5/8"	50'	30'	6 3/4"
						85'				
R-18778	"	22	6 11/16"	3 1/2"	64'		5 3/4"	75'	30'	5 3/4"
R-18778	"	23	6 11/16"	3 1/2"	30'		5 3/4"	50'	30'	5 3/4"
						94'				
R-18796	"	24	6 11/16"	3 1/2"	26'		5 3/4"	50'	30'	5 3/4"
	Bowen junk basket				2'					
						26' (Diamond)				
						2' (Bowen)				
	Bowen junk basket	25			2'	2' (Bowen)				
	Bowen junk basket	26			2'	2' (Bowen)				
R-18779	Diamond	27	6 11/16"	3 1/2"	13'		5 3/4"	50'	30'	5 3/4"
R-18779	"	28	6 11/16"	3 1/2"	9'		5 3/4"	50'	-	5 3/4"
						22'				
TOTALS:	Diamond					633'				
	Bowen junk basket					6'				
				Total Cored		639'				

DRILLSTEM TEST REPORT

Date: April 12, [illegible]
Lease: R[illegible] Mountain A[illegible]enal
Test Interval: [illegible]
Total Depth: [illegible]
Testing Company: H[illegible]
DST. No.:
Well No.: Di[illegible] W[illegible]ll No.
Formation: [illegible]
Well Elevation:
Witness: [illegible] Bal

Test Data

Tool Open For Initial Flow @ [illegible] A. M
Tool Closed For Initial Shut In @ [illegible]:20 A. M.
Tool Opened For Final Flow @ [illegible]:50 A. M.
Tool Closed For Final Shut In @ 12:50 P. M. -2:50 P. M.
Top Choke: 3/8"
Bottom Choke: 1/2"
Packers Set @
Cushion: N[illegible] Feet of -
Hydrostatic Pressure of Cushion - psi/foot x Feet = psi

				Time
Initial Hydrostatic Pressure:	[illegible]	[illegible]82	[illegible]	
Initial Flow Pressure:	202	2[illegible]2	[illegible]7	[illegible]
Initial Shut In Pressure:	5[illegible]2	4[illegible]2	[illegible]7	[illegible] min.
Final Flow Pressure:	1[illegible]7	[illegible]	[illegible]70	[illegible] min.
Final Shut In Pressure:	202	270	27[illegible]	*[illegible]20 min.
Pressure Bomb Number:	#2[illegible]2	#1[illegible]	[illegible]	
Depth of Bomb:	[illegible]552		[illegible]	
Bottom Hole Temperature:	Not reco[illegible]			

Gas to Surface in None minutes @ Mcf/Day; in minutes @ Mcf/Day; in - minute @ - Mcf/Day.
Recovery: 2[illegible] feet [illegible] slightly g[illegible] cut drilling mud.
Remarks:
Tool opened with [illegible] weak blow increasing to [illegible] blow in [illegible] minutes,
[illegible] remaining [illegible] until end of test.
*Packer failed after [illegible] hour of final shut in.

LAST MUD CHECK BEFORE TEST

Date: April 12, 1961 Test No.: 1

Drilling Mud:

Plastic Viscosity:	[illegible]	Chlorides (Cl^-):	5,000
Yield Point:		Sodium Chloride (Nacl):	
Initial Gel Strength:		Calcium (Ca):	
10 Minute Gel Strength:		Sulfate (SO_4):	
Weight:	9.5		
Fluid Loss:	[illegible].4		
pH:	9.0		
Mud Resistivity:	0.[illegible] Ω @ 84 °F		
Mud Filtrate Resistivity:	0.[illegible] Ω @ 64 °F		

Chromatograph Readings:

C_1	[illegible]M	C_4	0.5M
C_2	> [illegible]M	C_5+	Not Recorded
C_3	[illegible].5M		

Recovered Fluid

Sample No.:	1		
Plastic Viscosity:	304		
Yield Point:			
Initial Gel:			
10 Minute Gel:			
Weight:	8.2		
pH.	8.0		
Resistivity:	0.62 Ω	Ω	Ω
Temperature of Sample:	95°F		
Chloride (Cl^-):	7,500		
Sodium Chloride (Nacl):			
~~Calcium (Ca)~~: Rmf:	0.3[illegible]		
Sulfate (SO_4):			

Chromatograph Readings:

C_1		C_4	
C_2		$C+$	
C_3			

DRILLSTEM TEST REPORT

Date: [illegible] 2[illegible], 19[illegible]
Lease: [illegible] Mountain [illegible]
Test Interval: [illegible]
Total Depth: [illegible]
Testing Company: [illegible]

DST. No.: 2
Well No.: [illegible] Well No.
Formation: [illegible]
Well Elevation:
Witness: [illegible] *Bal*

Test Data

Tool Open For Initial Flow @ [illegible] M.
Tool Closed For Initial Shut In @ [illegible] M.
Tool Opened For Final Flow @ [illegible] M.
Tool Closed For Final Shut In @ 7[illegible] M. [illegible] M.
Cushion: None Feet of
Hydrostatic Pressure of Cushion - psi/foot x - Feet = psi

Top Choke: [illegible]
Bottom Choke: [illegible]
Packers Set @ [illegible]

				Time
Initial Hydrostatic Pressure:	N. R.	[illegible]90	[illegible]57	
Initial Flow Pressure:	[illegible]	[illegible]90	27[illegible]	5 min.
Initial Shut In Pressure:	1[illegible]7	[illegible]96	[illegible]	2[illegible] min.
Final Flow Pressure:	[illegible]	290	27[illegible]	60 min.
Final Shut In Pressure:	N. R.	[illegible]	[illegible]	[illegible] min.
Pressure Bomb Number:	#2[illegible]	#[illegible]7[illegible]	#[illegible]9	
Depth of Bomb:	[illegible]	[illegible]	[illegible]7	
Bottom Hole Temperature:	[illegible] F			

Gas to Surface in None minutes @ - Mcf/Day; in - minutes @ - Mcf/Day; in - minute @ - Mcf/Day.
Recovery: [illegible] feet [illegible] slightly [illegible]
Remarks: Tool opened [illegible]
[illegible]

LAST MUD CHECK BEFORE TEST

Date: [illegible] 2[illegible] 196[illegible] Test No.: 2

Drilling Mud:

Plastic Viscosity:	20	Chlorides (Cl^-):	7,500
Yield Point:		Sodium Chloride (Nacl):	
Initial Gel Strength:		Calcium (Ca):	960-1,000
10 Minute Gel Strength:		Sulfate (SO_4):	
Weight:	9.8		
Fluid Loss:	5.6		
pH:	9		
Mud Resistivity:	0.40 Ω @ ___ °F		
Mud Filtrate Resistivity:	0.42 Ω @ ___ °F		

Chromatograph Readings:

C_1 [illegible]M C_4 0.5-0.75M

C_2 0.[illegible]-2.[illegible]M C_{5+} 0.1-0.7M

C_3 [illegible].5-[illegible]M

Recovered Fluid

Sample No.:	1 (Top)	2 (Middle)	3 (Bottom)
Plastic Viscosity:	30	25	2[illegible]
Yield Point:	25	30	30
Initial Gel:	15	[illegible]3	14
10 Minute Gel:	35	48	48
Weight:	9.8	8.6	8.6
pH.	8	8	8
Resistivity:	0.48 Ω	0.56 Ω	0.6 Ω
Temperature of Sample:	70°F	70°F	70°F
Chloride (Cl^-):	5,800	7,200	7,600
Sodium Chloride (Nacl):			
~~Calcium (Ca)~~: Rmf	0.38	0.4[illegible]	0.4
~~Sulfate (SO_4)~~: Fluid Loss	4.4	5.4	5.6

Chromatograph Readings:

C_1 2[illegible]; 30; [illegible]0 C_4 2,[illegible], [illegible],200, 1,700

C_2 [illegible]5; 45; [illegible]5 C_{5+} [illegible], 1,200, 540

C_3 [illegible], 15; 9

DRILLSTEM TEST REPORT

Date: May 22, 1961
Lease: Rocky Mountain Arsenal
Test Interval: 9662
Total Depth: 9729
Testing Company: Schlumberger

DST. No.: 3
Well No.: Disposal Well No. 1
Formation: Lyons Sandstone
Well Elevation: 5202 K. B., 5187 G. L.
Witness: Bert A. Lear

Test Data

Tool Open For Initial Flow @ ______
Tool Closed For Initial Shut In @ ______
Tool Opened For Final Flow @ ______
Tool Closed For Final Shut In @ ______
Cushion: None Feet of -
Hydrostatic Pressure of Cushion - psi/foot x - Feet = - psi

Top Choke: -
Bottom Choke: -
Packers Set @ ______

				Time
Initial Hydrostatic Pressure:	5000			
Initial Flow Pressure:				15
Initial Shut In Pressure:				
Final Flow Pressure:				
Final Shut In Pressure:				
Pressure Bomb Number:				
Depth of Bomb:				
Bottom Hole Temperature:				

Gas to Surface in - minutes @ - Mcf/Day; in - minutes @ - Mcf/Day; in - minute @ - Mcf/Day.

Recovery: None

Remarks: Tool was completely plugged with lost circulation material.

Test was a misrun.

Test was run with the Schlumberger Formation Interval Tester.

DRILLSTEM TEST REPORT

Date: June 3, 1961
Lease: Rocky Mountain Arsenal
Test Interval: 9845-10016
Total Depth: 10016
Testing Company: Halliburton

DST. No.: 4
Well No.: Disposal Well No. 1
Formation: Fountain
Well Elevation: 5202 K. B, 5187 G. L.
Witness: Bert A. Lear

Test Data

Tool Open For Initial Flow @ 1:44 P. M.
Tool Closed For Initial Shut In @ -
Tool Opened For Final Flow @ -
Tool Closed For Final Shut In @ -
Cushion: 1700 Feet of Water
Hydrostatic Pressure of Cushion - psi/foot x - Feet = - psi

Top Choke: 3/8"
Bottom Choke: None
Packers Set @ 9845

				Time
Initial Hydrostatic Pressure:	4776	4779	4852	
Initial Flow Pressure:				
Initial Shut In Pressure:				
Final Flow Pressure:				
Final Shut In Pressure:				
Pressure Bomb Number:	1376	212	193	
Depth of Bomb:	9830	9850	10012	
Bottom Hole Temperature:	206°F			

Gas to Surface in - minutes @ ____ Mcf/Day; in ____ minutes @ ____ Mcf/Day; in ____ minute @ ____ Mcf/Day.

Recovery:

Remarks: Single packer test. Packer failed immediately when tool opened. Reset packer, failed again. Test was a misrun, probably due to communication around packers through fractures.

DRILLSTEM TEST REPORT

Date: June 4, 1961
Lease: Rocky Mountain Arsenal
Test Interval: 9830-10016
Total Depth: 10016
Testing Company: Halliburton

DST. No.: 5
Well No.: Disposal Well No. 1
Formation: Fountain
Well Elevation: 5202 K. B. 5187 G. L.
Witness: Bert A. Lear [signature]

Test Data

Tool Open For Initial Flow @ ______ Top Choke: ______
Tool Closed For Initial Shut In @ ______ Bottom Choke: ______
Tool Opened For Final Flow @ ______ Packers Set @ ______
Tool Closed For Final Shut In @ ______
Cushion: 2020 Feet of water
Hydrostatic Pressure of Cushion - psi/foot x - Feet = - psi

				Time
Initial Hydrostatic Pressure:	*	4829	4934	
Initial Flow Pressure:				
Initial Shut In Pressure:				
Final Flow Pressure:				
Final Shut In Pressure:				
Pressure Bomb Number:	1376	212	19[illegible]	
Depth of Bomb:	9813	9841	10012	
Bottom Hole Temperature:	206°F			

Gas to Surface in - minutes @ - Mcf/Day; in - minutes @ - Mcf/Day; in - minute @ - Mcf/Day.

Recovery: 2020' water cushion plus 1280' mud.

Remarks: Two packers. Packers failed immediately when tool opened. Reset packers, and failed again. Test [illegible] communication around packers through fractures.

* Bomb #1376 - Clock stopped.

DRILLSTEM TEST REPORT

Date: June 7, 1961
Lease: Rocky Mountain Arsenal
Test Interval: 9,862 - 10,057
Total Depth: 10,057
Testing Company: Halliburton

DST. No.: 6
Well No.: Disposal Well No. 1
Formation: Fountain
Well Elevation: 5202 KB, 5187 G.L.
Witness: Bert A. Lear

Test Data

Tool Open For Initial Flow @ 11:30 A.M.
Tool Closed For Initial Shut In @ 11:37 A.M.
Tool Opened For Final Flow @ 12:07 P.M.
Tool Closed For Final Shut In @ 1:07 P.M.
Cushion: 630 Feet of water
Hydrostatic Pressure of Cushion 0.433 psi/foot x 731 Feet = 317 psi

Top Choke: 1/8"
Bottom Choke: 7/8"
Packers Set @ 9857 and 9862

				Time
Initial Hydrostatic Pressure:	4,822	4,829	4,938	
Initial Flow Pressure:	1,191	Plugged	Plugged	7 min.
Initial Shut In Pressure:	[illegible],052	4,562	4,6[illegible]3	30 min.
Final Flow Pressure:	1,259	Plugged	4,127	60 min.
Final Shut In Pressure:	4,[illegible]	4,393	4,49[illegible]	120 min.
Pressure Bomb Number:	1,[illegible]76	212	193	
Depth of Bomb:	9,839	9,867	10,05[illegible]	
Bottom Hole Temperature:	220oF.			

Gas to Surface in None minutes @ - Mcf/Day; in - minutes @ - Mcf/Day; in - minute @ - Mcf/Day.
Recovery: 548' water cushion, 18[illegible]' mud cut water cushion, 1,646' mud.
Remarks:
Charts indicated that perforations were alternately plugging and clearing during the flow periods. The final buildup curve appears to be usable for calculations, based on visual examination.

Vol. of mud between tool & hole below packer = 195' x (0.1175 - 0.0330) = 16.[illegible] Bbls.
Vol. of mud lost due to leakage & resetting tool (est.) 5.00 Bbls.
Total 21.0[illegible] Bbls.
Mud recovered from formation = 19.11 - 21.0[illegible] = -1.97 Bbl.

LAST MUD CHECK BEFORE TEST

Date: Jan 7, 1961 Test No.: 6

Drilling Mud:

Plastic Viscosity: 26
Yield Point: 14
Initial Gel Strength:
10 Minute Gel Strength:
Weight: 9.5
Fluid Loss: 9.2
pH: 8
Mud Resistivity: 1.3 Ω @ °F
Mud Filtrate Resistivity: [illegible].2 Ω @ °F

Chlorides (Cl^-): 1,200
Sodium Chloride (Nacl): 1,650
Calcium (Ca): 1,000
Sulfate (SO_4):

Chromatograph Readings:

C_1 0.5M C_4 0.2M

C_2 Trace C_5+ 0.2M

C_3 .2M

Rmc [illegible]

Recovered Fluid

Sample No.:	Top	Middle	Bottom
Plastic Viscosity:	[illegible]0	48 - 60	50
Yield Point:			
Initial Gel:	10	15 - 10	20
10 Minute Gel:	60	90 - 90	1[illegible]0
Weight:	9.[illegible]	9.[illegible] - 9.4	9.4
pH.	8	7.5 - 7	7.5
Resistivity:	1.2 Ω	1.2 - 2.0 Ω	3.5 Ω
Temperature of Sample:	88° F	80°F - 67°F	60°F
Chloride (Cl^-):	600	600-800	600
Sodium Chloride (Nacl):			
Calcium (Ca):	800	600-880	880
Sulfate (SO_4):			

Chromatograph Readings:

C_1 450, 00, 480, 000 C_4 Tr, Tr, 50, 220

C_2 60, 0, 60, 420 C_5+

C_3 60, Tr, 0, 480

Rmf = 1. [illegible]° (Top)
[illegible] 85°
[illegible] 67°
[illegible] 66° (Bottom)

Bal

DRILLSTEM TEST REPORT

Date: [illegible]
Lease: Rocky Mountain Arsenal
Test Interval: 10,[illegible]-10,317
Total Depth: 10,31[illegible]
Testing Company: Halliburton

DST. No.: 7
Well No.: Pressure Injection Disposal Well No. 1
Formation: Fountain
Well Elevation: 5,202 KB, 5,187 GL
Witness: Al Samuels

Test Data

Tool Open For Initial Flow @ ________
Tool Closed For Initial Shut In @ ________
Tool Opened For Final Flow @ ________
Tool Closed For Final Shut In @ ________

Top Choke: 1/8"
Bottom Choke: 7/8
Packers Set @ ________

Cushion: 1,500 Feet of Water
Hydrostatic Pressure of Cushion 1,500 psi/foot x 0,433 Feet = 650 psi

				Time
Initial Hydrostatic Pressure:	4,24[illegible]	4,857	4,957	
Initial Flow Pressure:				
Initial Shut In Pressure:				
Final Flow Pressure:				
Final Shut In Pressure:				
Pressure Bomb Number:	1,376	212	193	
Depth of Bomb:	10,053	10,086	10,31[illegible]	
Bottom Hole Temperature:	-			

Gas to Surface in - minutes @ ________ Mcf/Day; in ________ minutes @ ________ Mcf/Day; in ________ minute @ ________ Mcf/Day.

Recovery: -

Remarks: Packers fa[illegible] [illegible]ediately. Misrun

DRILLSTEM TEST REPORT

Date:	June 18, 1961	DST. No.:	8
Lease:	Rocky Mountain Arsenal	Well No.:	Pressure Injection Disposal Well No. 1
Test Interval:	10,137-10,339	Formation:	Fountain
Total Depth:	10,339	Well Elevation:	5,202 KB, 5,187 GL
Testing Company:	Halliburton	Witness:	Howard H. Sells

Test Data

Tool Open For Initial Flow @ 9:18 AM — Top Choke: 1/8"
Tool Closed For Initial Shut In @ 9:25 AM — Bottom Choke: 7/8"
Tool Opened For Final Flow @ 9:56 AM — Packers Set @ ________
Tool Closed For Final Shut In @ 11:00 AM
Cushion: 1,500 Feet of Water
Hydrostatic Pressure of Cushion 1,500 psi/foot x 0.433 Feet = 650 psi

				Time
Initial Hydrostatic Pressure:	4,918	4,861	4,931	
Initial Flow Pressure:	774-846	1,004-1,012	1,091-1,123	7 minutes
Initial Shut In Pressure:	4,119	4,119	4,230	31 minutes
Final Flow Pressure:	848-1,230	1,050-1,308	1,221-1,435	64 minutes
Final Shut In Pressure:	4,069	4,083	4,193	120 minutes
Pressure Bomb Number:	1,376	212	193	
Depth of Bomb:	10,114	10,144	10,335	
Bottom Hole Temperature:	218°F			

Gas to Surface in None minutes @ ________ Mcf/Day; in ________ minutes @ ________ Mcf/Day; in ________ minute @ ________ Mcf/Day.

Recovery: 1,395' water, 93' muddy water, 1,188' mud.

Remarks: Had a weak blow when tool opened which continued throughout the test.

630' of 2 3/4" I.D. Drill Collars 630' x 0.0073 B/Ft. = 1.6 Bbls mud
180' of 3" I.D. Drill Collars : 180' x 0.0087 B/Ft. = 4.6 Bbls mud
378' of 4 1/2" X.H. Drill Pipe 378' x 0.0129 B/Ft. = 4.9 Bbls mud
Total = 11.1 Bbls mud recovered

DRILLSTEM TEST REPORT

Date: June 24, 1961

Lease: Rocky Mountain Arsenal

Test Interval: 10,336 - 10,542

Total Depth: 10,542

Testing Company: Halliburton

DST. No.: 9

Well No.: Pressure Injection Disposal No. 1

Formation: Fountain

Well Elevation: 5,202 KB, 5,187 GL

Witness: Alvin Samuels

Test Data

Tool Open For Initial Flow @ 10:58 A. M. Top Choke: 1/8"

Tool Closed For Initial Shut In @ 11:00 A. M. Bottom Choke: 7/8"

Tool Opened For Final Flow @ 11:30 A. M. Packers Set @ 10,331 & 10,336

Tool Closed For Final Shut In @ 12:09 P. M.

Cushion: 1,560 Feet of Water

Hydrostatic Pressure of Cushion 0.416 psi/foot x 1,560 Feet = 649 psi

				Time
Initial Hydrostatic Pressure:	5,088	Clock	5,206	
Initial Flow Pressure:	-	Stopped	843/843	2
Initial Shut In Pressure:	1,300	-	1,389	30
Final Flow Pressure:	603/685	-	833/848	32
Final Shut In Pressure:	1,505	-	1,634	90
Pressure Bomb Number:	1,376	212	193	
Depth of Bomb:	10,313	10,346	10,539	
Bottom Hole Temperature:	212°F			

Gas to Surface in - minutes @ - Mcf/Day; in - minutes @ - Mcf/Day; in - minute @ - Mcf/Day.

Recovery: 1,560' water cushion plus 129' mud.

Remarks:

Tool opened with no blow. By passed after 22 minutes. Had a weak blow which died in 5 minutes.

DRILLSTEM TEST REPORT

Date: July 3, 1963
Lease: Rocky Mountain Arsenal
Test Interval: 10,517 - 10,729
Total Depth: 10,729
Testing Company: Halliburton

DST. No.: 10
Well No.: Pressure Injection Disposal No. 1
Formation: Fountain
Well Elevation: 5,202 KB, 5,187 GL
Witness: Alvin Samuels and Bert A. Lear

Test Data

Tool Open For Initial Flow @ 9:30 A.M.
Tool Closed For Initial Shut In @ 9:33 A.M.
Tool Opened For Final Flow @ 10:03 A.M.
Tool Closed For Final Shut In @ 10:53 A.M.
Cushion: 1,700' Feet of Water
Hydrostatic Pressure of Cushion 0.416 psi/foot x 1,700 Feet = 707 psi

Top Choke: 3/8"
Bottom Choke: 7/8"
Packers Set @ 10,512 & 10,517

				Time
Initial Hydrostatic Pressure:	5,193	5,162	5,276	
Initial Flow Pressure:		593/597	861/861	3
Initial Shut In Pressure:	1,043	1,008	1/26	30
Final Flow Pressure:	693/693	723/743	850/865	50
Final Shut In Pressure:	1,278	1,365	1,476	120
Pressure Bomb Number:	1,376	212	193	
Depth of Bomb:	10,499	10,531	10,726	
Bottom Hole Temperature:	208°F			

Gas to Surface in - minutes @ - Mcf/Day; in - minutes @ - Mcf/Day; in - minute @ - Mcf/Day.
Recovery: 1,700' water cushion plus 90' of mud
Remarks:

No blow when tool opened. By passed tool. Had a weak blow which died in 15 minutes.

DRILLSTEM TEST REPORT

Date: July 9, 1961
Lease: Rocky Mountain Arsenal
Test Interval: 10,755 - 10,962
Total Depth: 10,962
Testing Company: Halliburton

DST. No.: 11
Well No.: Pressure Injection Disposal No. 1
Formation: Fountain
Well Elevation: 5,202 KB, 5,187 GL
Witness: Bert A. Leal

Test Data

Tool Open For Initial Flow @ 5:13 A.M.
Tool Closed For Initial Shut In @ 5:15 A.M.
Tool Opened For Final Flow @ 5:35 A.M.
Tool Closed For Final Shut In @ 6:35 A.M.
Top Choke: 3/8"
Bottom Choke: 7/8"
Packers Set @ 10,750 & 10,755
Cushion: 2,000 Feet of Water
Hydrostatic Pressure of Cushion 0.416 psi/foot x 2,000 Feet = 832 psi

				Time
Initial Hydrostatic Pressure:	5,389	5,427	5,550	
Initial Flow Pressure:	-	904/980	1012/1082	2
Initial Shut In Pressure:	1,770	1,764	1,840	20
Final Flow Pressure:	970/968	952/946	1045/1045	60
Final Shut In Pressure:	1,980	1,956	2,041	120
Pressure Bomb Number:	193	212	1,376	
Depth of Bomb:	10,735	10,765	10,595	
Bottom Hole Temperature:	216°F			

Gas to Surface in - minutes @ - Mcf/Day; in - minutes @ - Mcf/Day; in - minute @ - Mcf/Day.
Recovery: 2,000' of water cushion plus 90' of mud
Remarks:

Tool opened with a weak blow decreasing, to dead in 51 minutes.

DRILLSTEM TEST REPORT

Date: August 19, 1961
Lease: Rocky Mountain Arsenal
Test Interval: 11,096-11,439 (Cs. shoe @
Total Depth: 11,439 11,171)
Testing Company: Halliburton

DST. No.: 12
Well No.: Disposal Well No. 1
Formation: Fountain
Well Elevation:
Witness: Howard Sells

Test Data

Tool Open For Initial Flow @ 7:13 A.M.
Tool Closed For Initial Shut In @ 7:15 A.M.
Tool Opened For Final Flow @ 7:35 A.M.
Tool Closed For Final Shut In @ 8:05 A.M.

Top Choke: 3/8"
Bottom Choke: 7/8"
Packers Set @ 11,096

Cushion: 3040 Feet of water
Hydrostatic Pressure of Cushion 0.433 psi/foot x 3040 Feet = 1316 psi

				Time
Initial Hydrostatic Pressure:	5018	5035	5027	
Initial Flow Pressure:	1420/1414	1470/1465	1434/1432	2 min.
Initial Shut In Pressure:	2034	2067	2045	20 min.
Final Flow Pressure:	1418/1414	1470/1465	1434/1432	30 min.
Final Shut In Pressure:	1708	1756	1729	62 min.
Pressure Bomb Number:	221	193	212	
Depth of Bomb:	11077	11082	11112	
Bottom Hole Temperature:	200°F			

Gas to Surface in - minutes @ - Mcf/Day; in - minutes @ - Mcf/Day; in - minute @ - Mcf/Day
Recovery: 3040' water cushion plus 120' mud.
Remarks: No blow when tool opened. Tool was not plugged, but surface hose was plugged.

DRILLSTEM TEST REPORT

Date: September 5, 1961
Lease: Rocky Mountain Arsenal
Test Interval: 9,660-11,985(Csg. shoe
Total Depth: 11,985 11,171)
Testing Company: Halliburton

DST. No.: 13
Well No: Disposal Well No. 1
Formation: Fountain to pre-Cambrian
Well Elevation:
Witness: Alvin Samuels

Test Data

Tool Open For Initial Flow @ 8:22 A.M.
Tool Closed For Initial Shut In @ 8:25 A.M.
Tool Opened For Final Flow @ 8:55 A.M.
Tool Closed For Final Shut In @ 9:55 A.M.
Cushion: None Feet of -
Hydrostatic Pressure of Cushion - psi/foot x - Feet = - psi

Top Choke: 3/8"
Bottom Choke: 7/8"
Packers Set @ 9,660

				Time
Initial Hydrostatic Pressure:	4063	4086	4091	
Initial Flow Pressure:	810/1068	856/1117	840/1100	3 min.
Initial Shut In Pressure:	3859	3868	3870	30 min.
Final Flow Pressure:	901/2552	925/2565	925/2560	60 min.
Final Shut In Pressure:	3719	3732	3730	122 min.
Pressure Bomb Number:	221	193	212	
Depth of Bomb:	9640	9645	9677	
Bottom Hole Temperature:	214°F			

Gas to Surface in - minutes @ - Mcf/Day; in - minutes @ - Mcf/Day; in - minute @ - Mcf/Day.
Recovery: Recoved 5,330 feet of drilling mud.
Remarks: Opened with strong blow decreasing to good blow at end of test.

DRILLSTEM TEST REPORT

Date:	September 6, 1961	DST. No.:	14
Lease:	Rocky Mountain Arsenal	Well No.:	Disposal No. 1
Test Interval:	11,020-11,985 (Csg. shoe	Formation:	Fountain to Pre-Cambrian
Total Depth:	11,985 @ 11,171)	Well Elevation:	5187 G. L.; 5203 K. B.
Testing Company:	Halliburton	Witness:	J. Hardy Garrett, Jr.

Test Data

Tool Open For Initial Flow @	-	Top Choke:	3/8"
Tool Closed For Initial Shut In @	-	Bottom Choke:	1/4"
Tool Opened For Final Flow @	12:54 P.M.	Packers Set @	11,020
Tool Closed For Final Shut In @	3:30 P.M.		

Cushion: 2,000 Feet of water

Hydrostatic Pressure of Cushion 0.433 psi/foot x 2,000 Feet = 866 psi

				Time
Initial Hydrostatic Pressure;	5,029	5,050	*	-
Initial Flow Pressure:	-/1,771	-/1,844	*	-
Initial Shut In Pressure:	------------	NOT TAKEN	------------	------------
Final Flow Pressure:	-/3,463	-/3,508	*	156 min.
Final Shut In Pressure:	4,128	4,155	*	93 min.
Pressure Bomb Number:	221	193	212	
Depth of Bomb:	11,002	11,007	11,035	
Bottom Hole Temperature:	102°F			

Gas to Surface in - minutes @ - Mcf/Day; in - minutes @ - Mcf/Day; in - minutes @ - Mcf/Day.

Recovery: 2,000' water cushion plus 5,400' salt water

Remarks: Opened tool at 12:45 with no blow. Bypassed tool and reopened at 12:45 P.M. Had no blow at beginning of test, weak blow after 10 minutes, increasing to fair blow in 20 minutes and decreasing to a very weak blow at the end of the test.

* Clock stopped - no readings.

SPECIAL CORE ANALYSIS RESULTS
ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL

Sample No.	Depth Feet	Horizontal Permeability Millidarcys	Porosity Percent	Remarks
1	8,625	0.0	3.4	Dakota SS
2	30	0.0	4.6	"
3	60	0.0	8.6	"
4	63	0.0	5.3	"
5	9,619	0.0	3.8	Lyons SS
6	25	0.0	4.4	"
7	30	0.0	3.8	"
8	35	0.0	5.7	"
9	40	0.1	5.0	"
10	63	1.4	3.5	"
11	71	0.0	4.4	"
12	85	0.0	2.7	"
13	90	0.3	3.6	"
14	95	0.0	5.0	"
15	9,700	0.0	6.0	"
16	05	0.0	4.1	"
17	10	0.0	3.9	"
18	15	0.0	3.8	"

(Selected samples analyzed by Core Laboratories, Inc.)

Sample No.	Depth Feet	Horizontal Permeability Millidarcys	Porosity Percent	Remarks
19	9,720	0.0	6.0	Lyons SS
20	9,902	0.0	4.2	Fountain Arkose
21	10	0.0	6.1	"
22	20	0.0	1.9	"
23	24	0.0	1.0	"
24	10,125	0.0	4.2	"
25	135	0.0	3.9	"
26	144	0.0	6.7	"
27	156	0.0	3.9	"
28	392	0.0	2.8	"
29	398	0.0	2.6	"
30	400	0.0	4.7	"
31	596	0.0	3.6	"
32	605	0.0	2.9	"
33	623	0.0	6.0	"
34	627	0.0	2.3	"
35	805	0.3	3.5	"
36	811	0.0	3.0	"
37	823	0.0	1.7	"
38	830	0.0	2.9	"
39	11,048	0.0	2.1	"
40	065	0.0	4.7	"
41	071	0.0	2.1	"
42	130	0.0	5.6	"
43	138	0.6	6.8	"
44	140	0.9	6.0	'
45	144	0.3	5.5	"
46	147	0.0	3.9	"
47	153	0.1	3.0	"
48	165	0.0	3.4	"
49	173	0.0	3.1	"
50	457	0.0	2.2	"
51	462	0.2	5.8	"
52	11,465	0.2	4.8	"

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
LOGGING SUMMARY

Type Log	Induction-Electric			
Dates Run	3-15-61	5-21-61	8-1-61	9-4-61
First Reading	2,015'	9,719'	11,242'	11,990'
Last Reading	134'	2,020'	9,719'	11,166'
Footage Logged	1,881'	7,699'	1,523'	824'
Total Depth (Drlr.)	2,030'	9,729'	11,225'	11,985'
Hole Size	12 1/4"	11"	11"	6 3/4"

Type Log	Gamma-Ray Neutron	
Date Run	9-4-61	9-21-61
First Reading	11,988'	12,040'
Last Reading	50'	11,700'
Footage Logged	11,938'	340'
Total Depth (Drlr.)	11,985'	12,045'
Hole Size	6 3/4"	6 3/4"

Type Log	Sonic		
Date Run	5-21-61	8-1-61	9-4-61
First Reading	9,718'	11,234'	11,988'
Last Reading	2,020'	9,718'	11,166'
Footage Logged	6,698'	1,516'	822'
Total Depth (Drlr.)	9,729'	11,225'	11,985'
Hole Size	11"	11"	6 3/4"

Type Log	Microlog		
Date Run	3-15-61	5-21-61	9-4-61
First Reading	2,006'	9,717'	11,990'
Last Reading	134'	2,020'	11,166'
Footage Logged	1,872'	7,697'	824'
Total Depth (Drlr.)	2,030'	9,729'	11,985'
Hole Size	12 1/4"	11"	6 3/4"

Type Log	Temperature Log	
Date Run	5-21-61	9-4-61
First Reading	10'	11,990'
Last Reading	9,710'	9,500'
Footage Logged	9,700'	2,490'
Total Depth (Drlr.)	9,729'	11,985'
Hole Size	11"	6 3/4"

(All data taken from heading of log. See Volume III).

ROCKY MOUNTAIN ARSENAL
PRESSURE INJECTION DISPOSAL WELL
CASING AND HOLE SUMMARY

	Hole Size-Ft.	Depth of Hole-Ft.*	Casing Size-In.	Weight Lbs./ft.	Grade	Type	** Length of Casing-Ft.	*** Bottom of Cementing Shoe From G.L.
Surface String	24	139	20	94.0	H-40	ST&C	118	120
Intermediate String	17 1/2	2,031	13 3/8	54.5	J-55	ST&C	485	
				84.0	H-40	ST&C	807	
				54.5	J-55	ST&C	707	
							1,999	2,005
Long String	11	11,225	8 5/8	40.0	N-80	Extremeline	6,850	
				40.0	N-80	LT&C	2,037	
				44.0	N-80	LT&C	2,260	
							11,147	11,156
Liner ****	6 3/4	12,045	5 1/2	23.0	N-80	Extremeline	964	11,960
Tubing			5 1/2	23.0	N-80	Extremeline	8,998	

* Depth is measured from the kelly bushing. To convert to ground level subtract 15.5 feet.

** Length is measured from ground level and does not include the landing joint.

*** Difference between length of casing and bottom of cementing shoe represents any appurtenance other than casing included in the casing string; such as, cement shoe, float collars, etc.

**** Baash-Ross liner hanger.

Table 25